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COMPRESSION OF THE TRACHEOBRONCHIAL TREE BY THE ACTION OF THE VOLUNTARY RESPIRATORY MUSCULATURE IN NORMAL INDIVIDUALS AND IN PATIENTS WITH ASTHMA AND EMPHYSEMA*

By E. DEKKER, M.D.,† *and* R. C. LEDEBOER, M.D.‡
AMSTERDAM, HOLLAND

TALMA[26] in 1898 reported that asthmatic patients are often able to imitate at will the signs of an attack of asthma, when asked to do so. He also observed that normal persons were able to produce a wheezing expiration which seemed very similar to that which occurred during attacks of asthma. Since the wheezing sounds of asthma were similar in character over the entire thorax and changed simultaneously over the whole surface of the chest, he concluded that asthmatic wheezing had its origin in the trachea and larger bronchi, which were narrowed by a voluntary action. He quoted and confirmed the laryngoscopic observation of Van Hoek that in attacks of asthma the posterior wall of the trachea protruded into the lumen during expiration. Talma[26] thought that this narrowing of the larger airways was caused by a voluntary contraction of the smooth musculature.

In 1906 Strübing[22] confirmed that patients with asthma as well as normal subjects could produce a voluntary wheezing expiration at will. He, however, gave a different explanation and suggested that the origin of the tracheobronchial narrowing during the wheezing expiration might be the passive compression of the larger airways by a high intrathoracic pressure which was due to an abnormal breathing pattern. The influence of intrathoracic pressure on tracheobronchial compression had already been lucidly discussed by Einthoven.[9] That patients with asthma are able to imitate their attacks when asked to do so has recently been re-emphasized.[8] Dekker and Groen[4,6] confirmed the earlier observation that normal individuals can also learn to produce an asthma-like wheezing expiration at will. In their work they followed the instructions of Strübing:[22] "The forced expiratory movements of the asthmatic can best be learned in the following way. After a short inspiration one

* This investigation was supported in part by the Organisation for Health Research T.N.O.
† Second Medical Service, Wilhelmina Gasthuis, Amsterdam, Holland.
‡ University Department of Roentgenology, Wilhelmina Gasthuis, Amsterdam, Holland.

gives a slight cough. The cough movement is not completed, however, but instead a strong pressing and prolonged expiration is substituted. If one wishes to imitate the asthmatic breathing these respiratory movements are continued alternating with short inspiratory movements." By this method 16 out of 18 consecutive normal volunteers learned to wheeze at will within a few minutes.[4]

The mechanism of this "voluntary wheezing expiration" was studied for the following reasons: It can easily be produced at will both by asthmatic patients and by normal individuals which makes it suitable for an experimental approach. It was expected that study of the mechanism of voluntary wheezing expiration might throw some light on the pathophysiology of asthma and emphysema and on the problem as to whether the expiratory narrowing of the tracheobronchial tree during cough and in asthma and emphysema[4] is active[18–20] or passive[2,10,13,14,21,23,24,30] in nature.

In this paper roentgenologic studies and measurements are presented of the diameters of the trachea and main bronchi during voluntary wheezing in normal individuals and in patients with asthma and emphysema, supplemented by some observations during spontaneous and induced attacks of asthma.

METHOD AND MATERIAL

In order to avoid an influence of the contrast medium on the dynamics of air flow in the bronchi and on the reflex behavior of its walls,[10,24] the roentgen studies were done without contrast filling of the trachea and main bronchi.

Short time exposures were made in four projections: lateral, posteroanterior and both oblique projections, during respiratory arrest and—as much as possible—in the middle of the expiratory movement during "voluntary wheezing expiration." In a few cases observations were made during attacks of asthma which were either spontaneous or induced by the inhalation of an aerosol of histamine or of an allergen extract.

In order to obtain well defined images of the moving objects, an exposure time of only 0.04 second was used in combination with high voltage (125 kv.) and high-speed intensifying screens.

Twenty patients were thus roentgenographed during voluntary wheezing expiration, 10 who were normal and 10 who had asthma and/or emphysema. Of the latter group, 4 were examined during severe attacks of asthmatic dyspnea, 2 spontaneous and 2 induced. Direct measurements were carried out of the diameter of the air column in the trachea and when possible in the main bronchi. The outlines were traced on transparent paper and reproduced photographically on a smaller scale.

RESULTS

ROENTGEN FINDINGS

The roentgen changes in the major airways during the voluntary wheezing expiration in normals can be described together with those observed in asthmatic patients during voluntary wheezing expiration, or during spontaneous or induced attacks of severe dyspnea, as no essential differences between these groups were found, although there was some individual variation in the degree of the changes. Figures 1–6 illustrate the findings.

1. The *trachea* was considerably *narrowed* on all roentgenograms during voluntary wheezing expiration as compared to its configuration during respiratory arrest. This was noted especially on the posteroanterior roentgenogram. Sometimes a double contour could be observed near the posterior tracheal wall which was interpreted as the shadow of the protruding membranous part of the wall. The cartilage-supported part of the tracheal wall was also compressed as could be concluded from the diminution in its sagittal diameter.

This narrowing during expiration often differed considerably along the course of the trachea, giving its outlines an irregular wave-like appearance. The compression could frequently be observed to continue along the lower cervical part of the trachea (Fig. 1, *A* and *B*; 3, *A* and *B*; and 4, *A* and

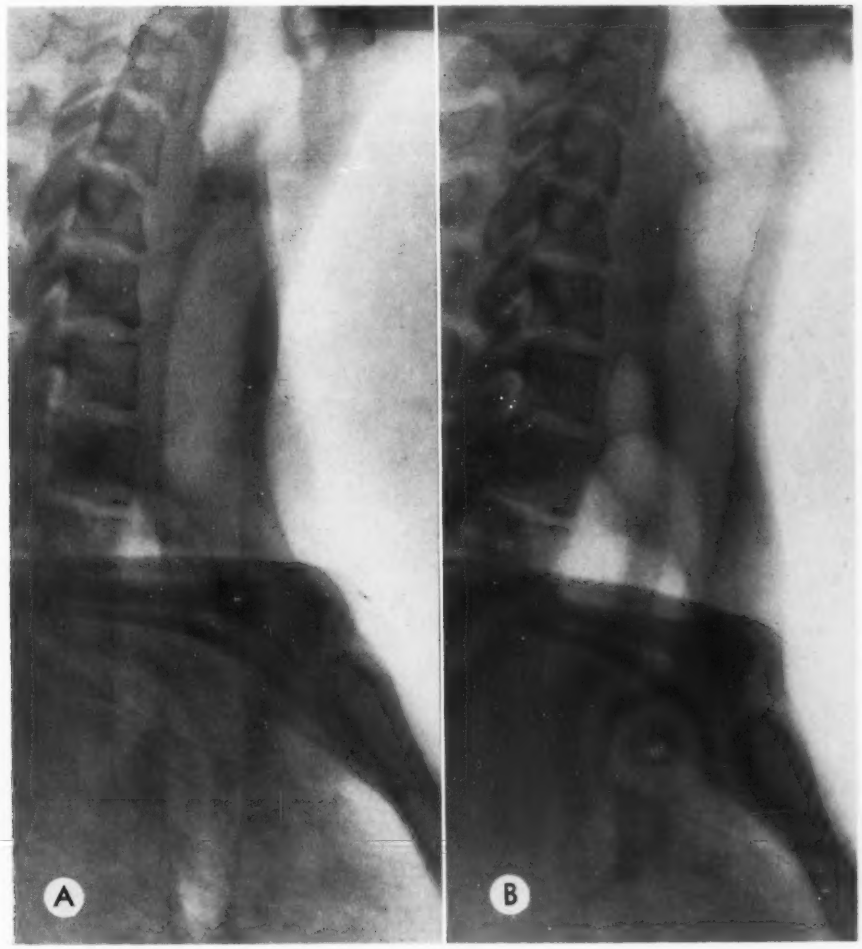

Fig. 1. (*A*) Roentgenogram of the trachea of a normal subject during respiratory arrest. (*B*) The cervical and intrathoracic parts of the trachea are narrowed and the cervical part is displaced in the ventral direction during "voluntary wheezing expiration."

B). There was a rather abrupt transition from the compressed lower to the wide open upper cervical part of the trachea, where the lumen retained its original size.

2. The *main bronchi* also appeared markedly narrowed during the wheezing expiration. In some of the subjects the lumina were reduced to a few millimeters (Fig. 2*B*). This narrowing of the major airways could easily be seen on fluoroscopy. It started very shortly after the beginning of the expiratory movement and continued almost throughout its entire duration.

In addition it was often possible to observe the dynamic behavior of the esophagus. In the right anterior oblique projection the wall of the esophagus and the posterior tracheal wall appeared as a common shadow, a few millimeters wide, which moved in a forward direction during the expiration.

3. The trachea became *shortened* during the wheezing expiration. The distance from the glottis to the bifurcation was reduced up to 5 cm. The bifurcation was driven upward and with it some other mediastinal structures were displaced. The aortic arch often shifted several centimeters craniad. The glottis and other laryngeal structures, on the other hand, descended. This shortening of the trachea was probably responsible for another phenomenon which could sometimes be observed: "ribbing" outline of the walls with clear demonstration of the

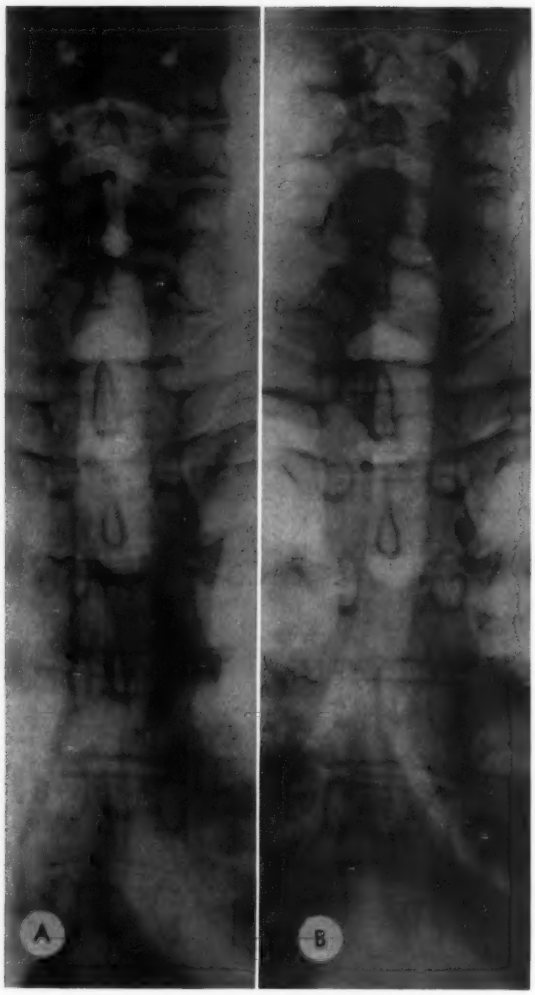

FIG. 2. (*A*) Anteroposterior roentgenogram of a normal subject during respiratory arrest. (*B*) During "voluntary wheezing expiration" the trachea and main bronchi are narrowed; the trachea is shortened and the glottis is open.

cartilaginous rings (Fig. 4, *A* and *B*).

4. During wheezing expiration the trachea altered its *position*. In the lower cervical part it was generally displaced forward (Fig. 1, *A* and *B* and 4, *A* and *B*). The shadow of the soft tissues of the lower neck was increased on the posteroanterior roentgenogram. The trachea also altered its course within the thorax, although its behavior here was much more variable (Fig. 7 and 8).

5. During wheezing expiration the *glottis* was wide open. This is clearly seen on the posteroanterior roentgenograms (Fig. 2, *A* and *B*).

6. The *pharynx* was widened in most of the subjects during voluntary wheezing expiration (Fig. 3, *A* and *B*; and 4, *A* and *B*). The hyoid bone was displaced caudally over about one cervical vertebra and so were the cartilages of the larynx.

7. On some roentgenograms the *larger intrapulmonary bronchi* near the hilus were visible. These also showed considerable narrowing during the wheezing expiration.

Figures 7 and 8 are line drawings illustrating the expiratory deformities during "voluntary wheezing expiration" in normal individuals and in patients with asthma and emphysema. Similar narrowings were demonstrated during episodes of dyspnea in these patients as illustrated by Figure 9.

QUANTITATIVE DATA

Tables I and II summarize some representative measurements of the tracheal lumen as seen on roentgenograms. Only those measurements are given which could be obtained with sufficient confidence in view of the comparatively weak contrast of the air column in the airways.

From these measurements it can be calculated that the frontal diameter of the tracheal lumen in normal individuals and in asthmatic patients was reduced from a mean value of 18.2 mm. to 13.4 mm. during voluntary wheezing expiration. The mean anteroposterior diameter was at the same time reduced from 19.1 to 12.5 mm.

Figure 10 is a schematic representation of a tracheal lumen at rest and in the narrowed state (natural size) based on these measurements.

DISCUSSION

During normal respiration the tracheobronchial tree changes its diameter: during inspiration the lumina are wide; during expiration they are narrowed. This has been described by a number of investigators.[10,12,15,16,24] These investigators were, however, mostly concerned with what might be called *static* changes in the diam-

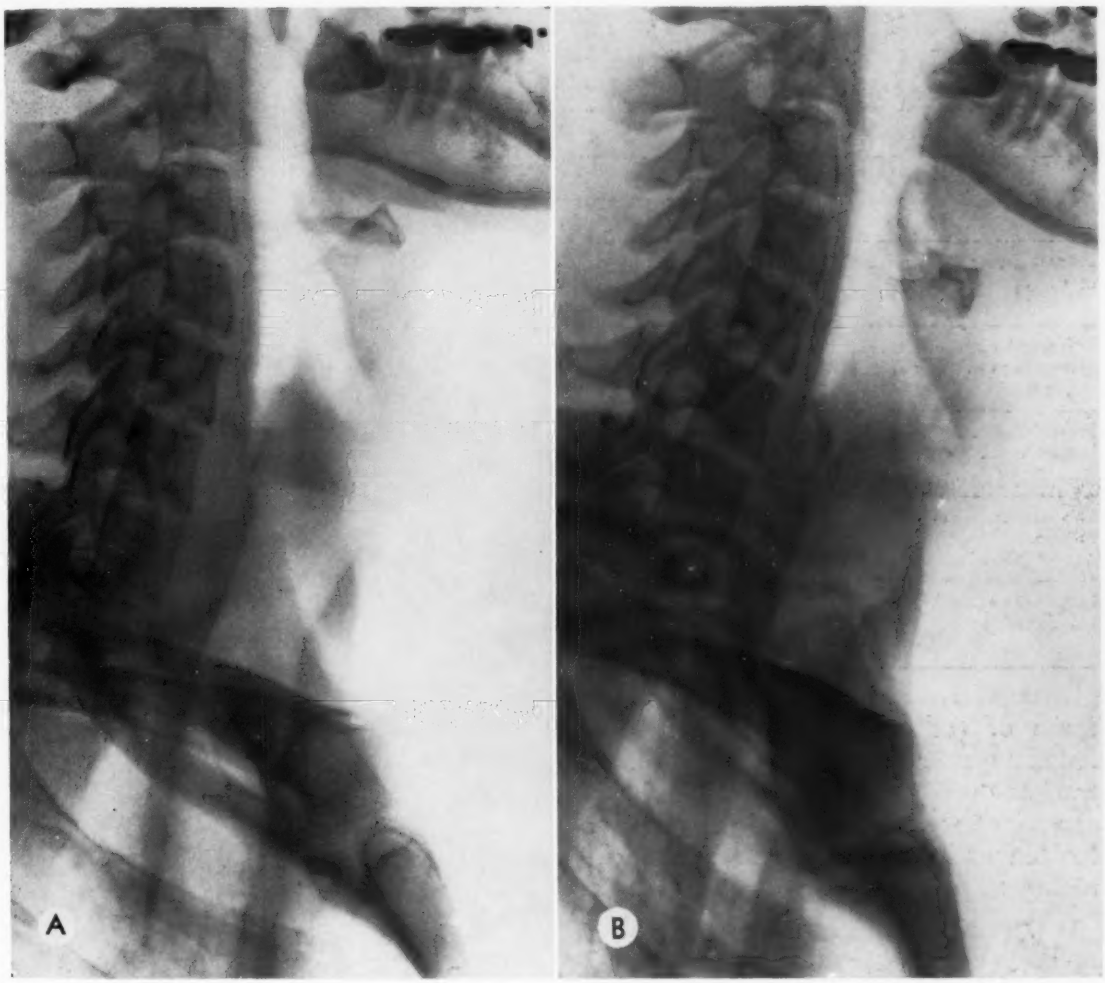

Fig. 3. (*A*) Roentgenogram of an asthmatic patient during respiratory arrest. (*B*) Narrowing of the cervical and intrathoracic part of the trachea occurs during "voluntary wheezing expiration."

eter of the bronchi. They based their studies on the comparison of roentgenograms taken during inspiratory and expiratory respiration *arrest*. Comparatively few studies have been performed on the *dynamic* changes in tracheobronchial diameter during physiologic or pathologic respiratory movements.

Dekker and Groen[4,6] have summarized some of the data from the bronchoscopic literature from which it can be concluded that under certain physiologic and pathologic conditions, *i.e.*, during attacks of asthma or in patients with emphysema and serious dyspnea, considerable narrowing of the trachea and cartilage-supported airways can be observed during expiration. The membranous part of the walls protrudes into the lumen giving it a triangular or crescent shape. There are also several roentgenologic observations of marked changes in diameter. Franklin and Janker[11] noted in the cat, during the expiratory phase of coughing, a reduction of the volume of the bronchi to about one seventh of normal size. Weltz[28] using kymography registered a difference of 18 mm. in the diameter of the trachea between inspiration and expiration in a patient during an attack of asthma. Stutz[23] and Weber[27] have also observed a difference in the diameter of the trachea during cough and during at-

TABLE I

MEASUREMENTS FROM ROENTGENOGRAMS OF AIRWAY LUMINA (IN mm.) IN NORMAL INDIVIDUALS AT REST AND DURING VOLUNTARY WHEEZING EXPIRATION

		H.P.	A.D.	M.F.	P.R.	F.M.	A.W.	J.M.	E.A.	E.D.	R.B.	Average	Per Cent
Sagittal diameter of trachea in upper thoracic aperture	at rest	26	26	25	26	25	29	27	—	30	24	26	
	wheezing	16	15	16	18	20	19	24	—	—	15	18	69
Frontal diameter of trachea at T2	at rest	22	21	20	20	20	24	20	22	24	—	21	
	wheezing	17	20	16	14	16	16	14	12	21	—	16	76
Left anterior oblique diameter of trachea 7 cm. below thyroid cartilage	at rest	24	19	20	23	—	26	23	20	19	—	22	
	wheezing	11	12	13	16	—	12	19	15	15	—	14	64
Frontal diameter of right main bronchus	at rest	20	—	—	17	19	19	14	—	—	—	18	
	wheezing	2	—	—	9	15	14	11	—	—	—	10	56
Frontal diameter of left main bronchus	at rest	12	14	—	14	14	14	14	—	—	—	14	
	wheezing	4	—	4	9	10	7	10	—	—	—	7	50
Length of trachea from glottis to bifurcation	at rest	180	—	—	165	—	180	160	—	—	—	171	
	wheezing	145	—	—	150	—	128	130	—	—	—	138	81

tacks of asthmatic dyspnea.[25] Dayman[2] found a momentary collapse of the thoracic trachea during cough in man. Similar observations were made by Ross *et al.*[21] and Holden and Ardran[14] by means of cineroentgenography during cough. These "dynamic" caliber changes of the tracheobronchial tree, apart from the difference in causative mechanism, vary considerably from the "static" caliber changes.[14,24]

The "static" changes are predominantly located in the smaller, more peripheral air-

TABLE II

MEASUREMENTS FROM ROENTGENOGRAMS OF AIRWAY LUMINA (IN mm.) IN ASTHMATIC PATIENTS AT REST AND DURING VOLUNTARY WHEEZING EXPIRATION

		L.P.	N.P.	A.B.	J.C.	J.D.	J.P.	K.S.	D.T.	C.D.	P.W.	Average	Per Cent
Saggital diameter of trachea in upper thoracic aperture	at rest	24	28	25	28	22	—	24	21	22	22	24	
	wheezing	17	12	20	27	10	—	8	14	15	14	15	63
Frontal diameter of trachea at T2	at rest	23	23	18	29	18	24	23	17	20	21	22	
	wheezing	22	15	16	22	12	10	16	12	14	16	16	73
Left anterior oblique diameter of trachea 7 cm. below thyroid cartilage	at rest	24	24	22	23	18	23	25	18	22	24	22	
	wheezing	7	11	17	6	12	11	11	15	10	12	11	50
Frontal diameter of right main bronchus	at rest	—	—	—	—	12	16	16	—	15	—	15	
	wheezing	—	—	—	—	—	10	—	—	11	—	11	73
Frontal diameter of left main bronchus	at rest	—	—	—	—	11	11	15	—	13	—	13	
	wheezing	?4	—	—	—	2	11	14	—	10	—	9	69
Length of trachea from glottis to bifurcation	at rest	—	—	—	—	170	215	170	200	175	—	186	
	wheezing	—	—	—	—	—	215	170	180	155	—	180	97

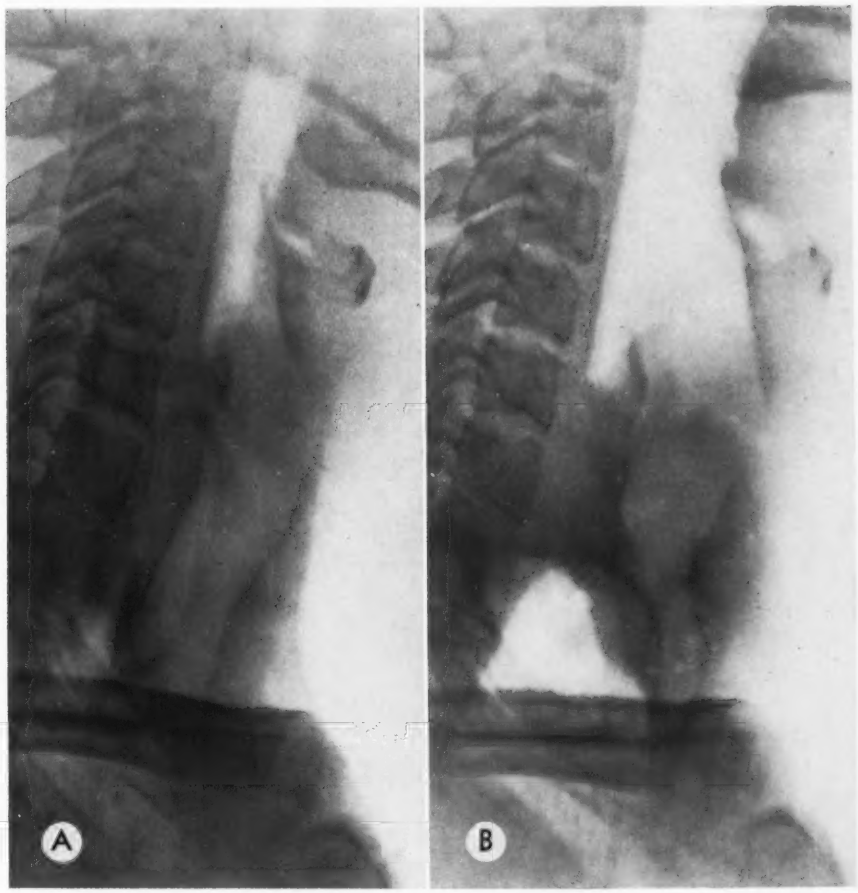

Fig. 4. (*A*) Roentgenogram of an asthmatic patient during respiratory arrest. (*B*) During "voluntary wheezing expiration" marked narrowing of the cervical part of the trachea occurs.

ways, whereas the "dynamic" changes appear to be located mainly in the more central airways.[14,24] The occurrence of strong dynamic respiratory caliber changes during cough and during attacks of dyspnea in patients with asthma and emphysema seems firmly established.

We have not been able, however, to find any studies on the influence of "voluntary wheezing expiration" on the diameter of the trachea and main bronchi in normal individuals and in patients with asthma. It seems that under these circumstances a similar considerable narrowing of the larger airways occurs. In other words, even normal individuals are able to produce a strong expiratory narrowing of the larger cartilage-supported airways without preceding closure of the glottis. These observations may contribute to several problems which are at present under discussion.

One of these problems has been the mechanism causing the "dynamic" caliber changes. Most authors[2,10,13,14,21,23,24,30] have accepted passive compression of the airways by high intrathoracic pressure as an explanation for the tracheobronchial narrowing. In coughing, for example, during the preceding phase of glottis closure, a high pressure of over 100 mm. Hg builds up in the thoracic cage.[21,29] Immediately after the explosive opening of the glottis, intraluminal pressure in the major airways is assumed to drop almost to zero whereas intrathoracic pressure is maintained for a short while, causing a great transmural pressure difference across the wall of the airways which are then externally compressed.

This view has been challenged by di Ri-

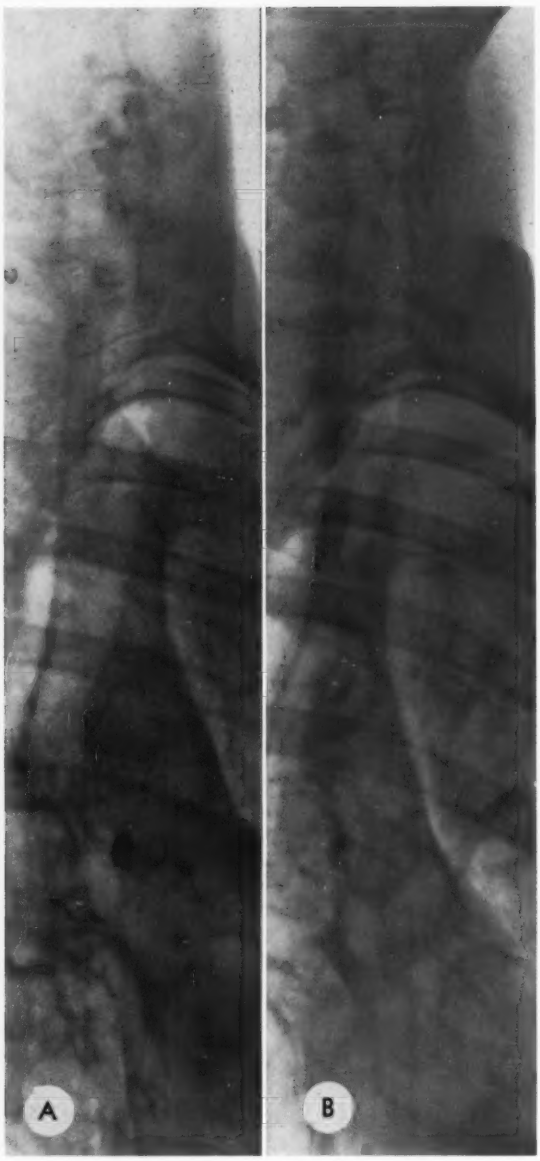

FIG. 5. (*A*) Trachea of an asthmatic patient in the right anterior oblique projection during respiratory arrest. (*B*) During "voluntary wheezing expiration" the intrathoracic part of the trachea is narrowed.

enzo[18–20] who ascribed the tracheobronchial dynamism during cough to an active reflex peristaltic movement of the muscular coats of the bronchial walls. Ross, Gramiak and Rahn[21] recorded intrapleural pressure and rate of air flow during a cough simultaneously by high speed cineroentgenography of the chest which permitted the visualization of the trachea. These investigators observed changes in the apparent diameter of the trachea which were synchronous with changes in intrapleural pressure once the glottis had opened. Although they obtained no evidence of a peristaltic movement along the bronchial tree, these authors prudently considered their evidence as insufficient to conclude that high intrapleural pressure is the only mechanism responsible for changes in tracheobronchial diameters during cough. They expressed the need for the investigation of an analogous situation not involving the cough reflex in order to obtain evidence that reflex bronchomotion is not responsible for the reduction in airway caliber. Our observations on voluntary wheezing expiration seem to give further support to their hypothesis of a passive compression.

The intrathoracic pressure during voluntary wheezing expiration was shown by Dekker, Defares and Heemstra[7] to rise to about 70 mm. Hg, a value which compares well with the results of Ross *et al.*,[21] obtained during coughing. Simultaneous direct measurement of endobronchial pressure by means of a special endobronchial catheter allowed an estimation of the transmural pressure which was compressing the airways at different levels[4] (Table III). It was shown *in vitro* during compression experiments on human tracheobronchial tissue obtained post mortem that such transmural pressures could considerably narrow the respective parts of the bronchial tree.[4]

It would seem at first sight that the narrowing of the trachea would cause a high airflow resistance. Our roentgenographic measurements provided a basis for a tentative calculation[1] of air flow resistance in the

TABLE III

TRANSMURAL PRESSURE, COMPRESSING THE AIRWAYS DURING VOLUNTARY WHEEZING EXPIRATION[4]

	mm. Hg
Larger intrapulmonary bronchus	15
In or near mean bronchus	55
Upper intrathoracic part of trachea	68

Fig. 6. (*A*) Trachea of an asthmatic patient in the left anterior oblique projection during respiratory arrest. (*B*) During "voluntary wheezing expiration" and (*C*) during a spontaneous attack, a narrowing of the trachea and main bronchi occurs.

trachea in its normal and in its compressed state. Table IV gives a summary of the results of such calculation based on the dimensions shown in Figure 10. From this calculation it can be seen that the air flow resistance of the normal trachea is almost negligible. The calculated air flow resistance of the narrowed trachea is also negligible at low air speeds and even in the compressed state its value remains comparatively low. Obviously, the caliber of the human trachea contains a wide margin of safety.[17,30] Tracheobronchial compression by high intrathoracic pressure may also play a role in the pathophysiology of attacks of dyspnea in patients with asthma and emphysema. In asthmatic patients primary narrowing of the smaller peripheral bronchi will tend to raise the intrathoracic pressure during expiration. High intrathoracic pressure will tend to cause further compression of the airways, thus initiating a vicious circle.[9] In this case high intrathoracic pressure can be considered to be a compensatory phenomenon. Since our results indicate that narrowing of the airways can also be brought about in asthmatic patients by a primary action of the voluntary respiratory musculature raising the intrathoracic pressure, the alternative possibility, that at least in some attacks of asthma a primarily disturbed breathing

TABLE IV

CALCULATED AIR FLOW RESISTANCE IN THE TRACHEA IN ITS NONCOMPRESSED AND COMPRESSED STATES

	Air flow velocity in l./sec.			
	0.25	0.5	1	2
Air flow resistance in cm. H_2O/l./sec.				
Noncompressed trachea	0.0082	0.0082	0.017	0.035
Compressed trachea	0.061	0.072	0.17	0.35

mechanism may narrow the airways, deserves further consideration. Although it has been possible to provoke and register reproducible psychogenic attacks of asthma in the laboratory,[3,5] hardly any research has been done on the nature of the pathways conveying the emotional influences from the central nervous system to the lungs. Among several mechanisms which might be involved in these phenomena, tracheobronchial compression of the airways caused by a primary disturbance of the action of the voluntary respiratory musculature deserves further consideration and study.

SUMMARY

1. Roentgenographic studies made during "voluntary wheezing expiration" revealed that normal individuals as well as patients with asthma and emphysema can voluntarily narrow their tracheobronchial tree to a considerable extent.

2. This narrowing was probably caused

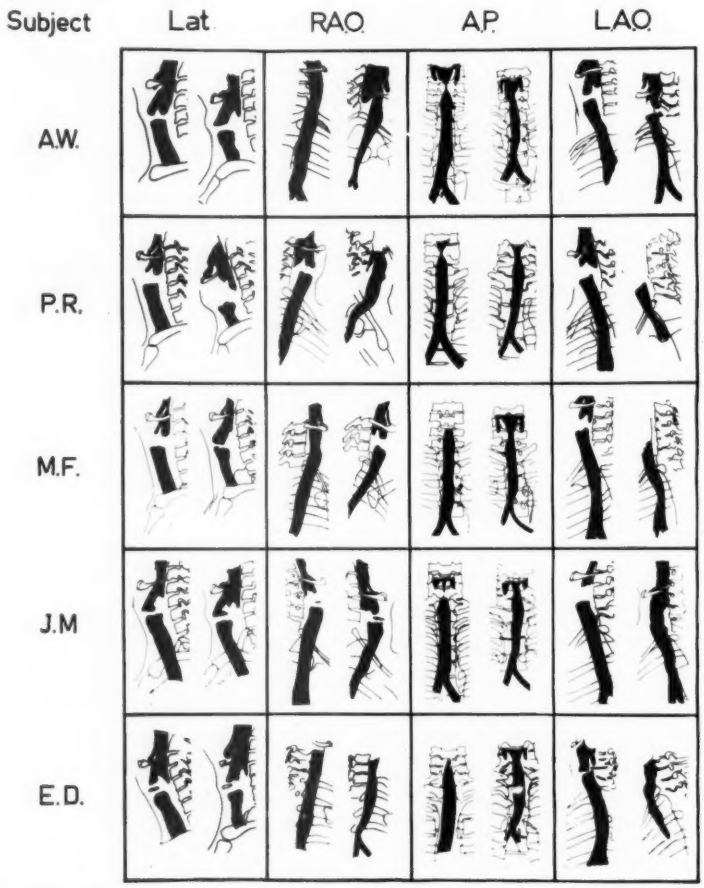

FIG. 7. Line drawings of the trachea and main bronchi of normal subjects in the lateral, right anterior oblique, anteroposterior and left anterior oblique projections during respiratory arrest (left) and during "voluntary wheezing expiration" (right).

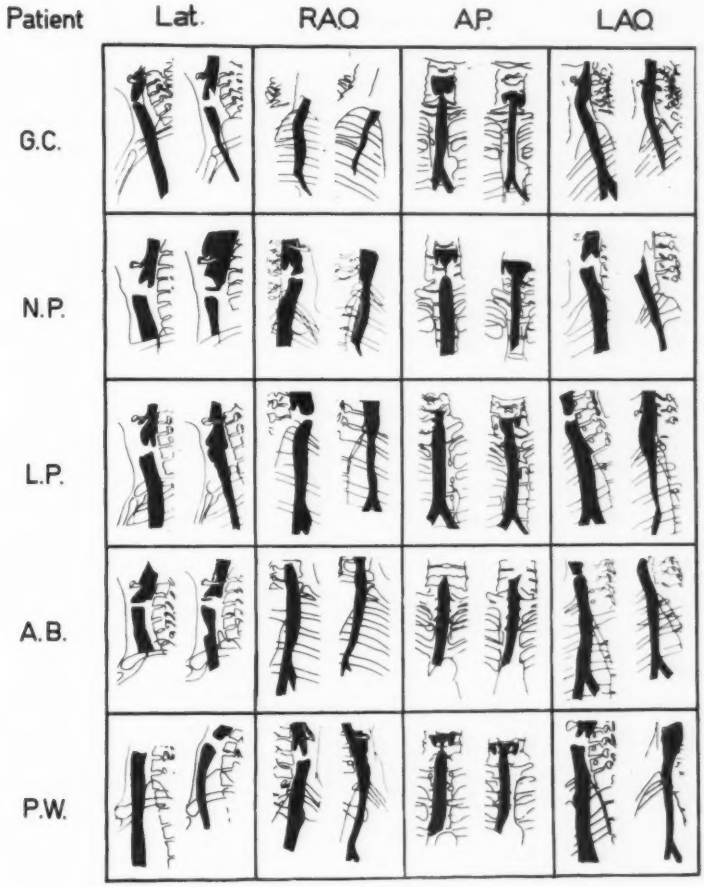

Fig. 8. Line drawings of the trachea and main bronchi of asthmatic patients in the lateral, right anterior oblique, anteroposterior and left anterior oblique projections during respiratory arrest (left) and during "voluntary wheezing expiration" (right).

by a high intrathoracic pressure which passively compressed the airways.

3. Calculations revealed that the air flow resistance was almost negligible in the normal trachea and remained low, even in its compressed state.

E. Dekker, M.D.
Department of Cardiology and Clinical Physiology
Wilhelmina Gasthuis
Amsterdam, Holland

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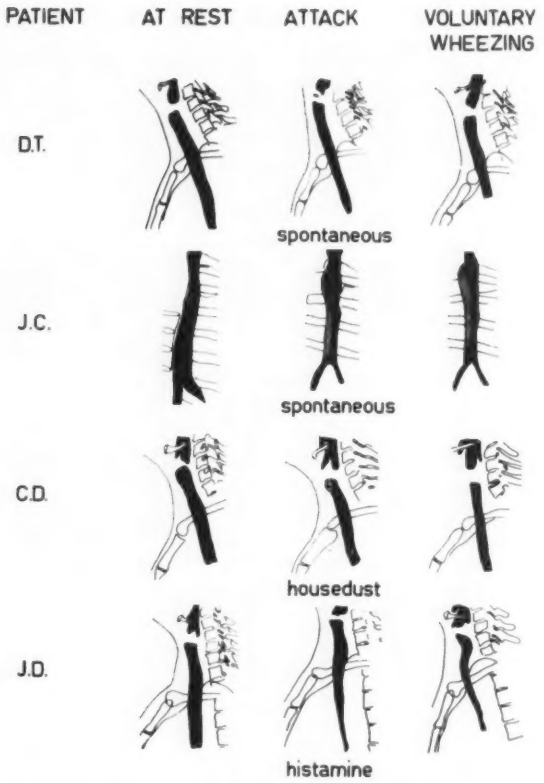

FIG. 9. Line drawings of narrowing of the trachea of asthmatic patients during asthmatic attacks (both spontaneous and induced) and during "voluntary wheezing expiration," as compared to at rest.

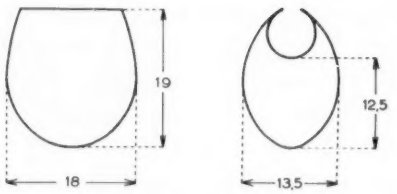

FIG. 10. Schematic representation of the trachea in its normal and compressed states, based on the means of the roentgen measurements at the second thoracic vertebra (natural size).

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ANGIOCARDIOGRAPHY IN BULLOUS EMPHYSEMA: ITS ROLE IN SELECTION OF THE CASE SUITABLE FOR SURGERY*

By CAPT. KENNETH M. JENSEN, USAF (MC), LAURENCE MISCALL, M.D., *and* ISRAEL STEINBERG, M.D.
NEW YORK, NEW YORK

SURGICAL treatment of bullous emphysema has become generally accepted as being beneficial in selected patients.[8,17–19,29] In this report, cases illustrating the role of angiocardiography in the diagnosis of bullous emphysema[18,28] and in the selection of the patient suitable for surgery are presented. Thereby, criteria for the use of angiocardiography for treatment of bullous emphysema are promulgated.

MATERIAL AND METHOD

Sixty adult patients, referred for angiocardiography in order to evaluate the type and degree of emphysema (generalized or bullous), form the basis of this study. The clinical, laboratory and roentgen features of each case were reviewed. Of these, 8 were selected for detailed presentation because they best serve to illustrate the role of angiocardiography in the selection of the patient with emphysema that can be benefited by surgery. Angiocardiography was done in the erect frontal position utilizing 14×17 inch film in order to include the whole of the lungs. The stereo shifter with grid cassettes permitted two roentgenograms per injection.[21] Opacification of the right heart structures, pulmonary artery and pulmonary arterial tree was secured on the first roentgenogram which was usually exposed three and one-half seconds after the beginning of injection. The other roentgenogram was exposed at seven and one-half seconds and provided a view of the opacified pulmonary veins, left atrium and ventricle. Serial studies at one second intervals were made in some instances. The contrast substance was urokon sodium (70 per cent) in 50 cc. doses. No severe reactions occurred.

REPORT OF CASES

CASE 1. *Generalized and bullous emphysema; surgery contraindicated because of severe generalized emphysema.* A fifty-two year old male (N.Y.H. No. 365302) was admitted on April 3, 1955, because of a productive cough and progressive dyspnea of eight years' duration. During that time he had had four hospital admissions for acute bronchitis, bronchopneumonia and pneumonia. He also had had "double pneumonia" at the age of thirteen years. In the past two years he had developed polycythemia, cor pulmonale and congestive heart failure. Two weeks prior to admission there was increased cough, blood streaked sputum and right middle lobe pneumonia. On examination, the patient was acutely and chronically ill, orthopneic and gasping with wheezing respirations at the rate of 40 per minute. Cyanosis of the lips and nailbeds was marked. The chest was barrel-shaped, hyper-resonant and use of the accessory muscles of respiration was evident. The breath sounds were distant; coarse rhonchi and wheezes were heard in the upper parts of the chest with fine inspiratory and expiratory rales at the bases. The heart was not enlarged. The liver was 9 cm. below the right costal margin and the ankles were edematous.

The conventional roentgenogram of the chest (Fig. 1*A*) revealed a long thorax with markedly distended lungs. An angiocardiogram (Fig. 1*B*), made three years prior to admission, showed a large pulmonary artery and branches with meager and wiry pulmonary arterial circulation to the upper lobes which appeared to narrow abruptly in the mid-zone of the thorax ("the winter tree pattern"). The pulmonary arterial circulation to the lower lung fields was delayed and extended only a slight distance beyond the hilus. Two and a half seconds later (Fig. 1*C*)

* From the Department of Radiology and the Private Patient Surgical Service, The New York Hospital—Cornell Medical Center, New York, New York.
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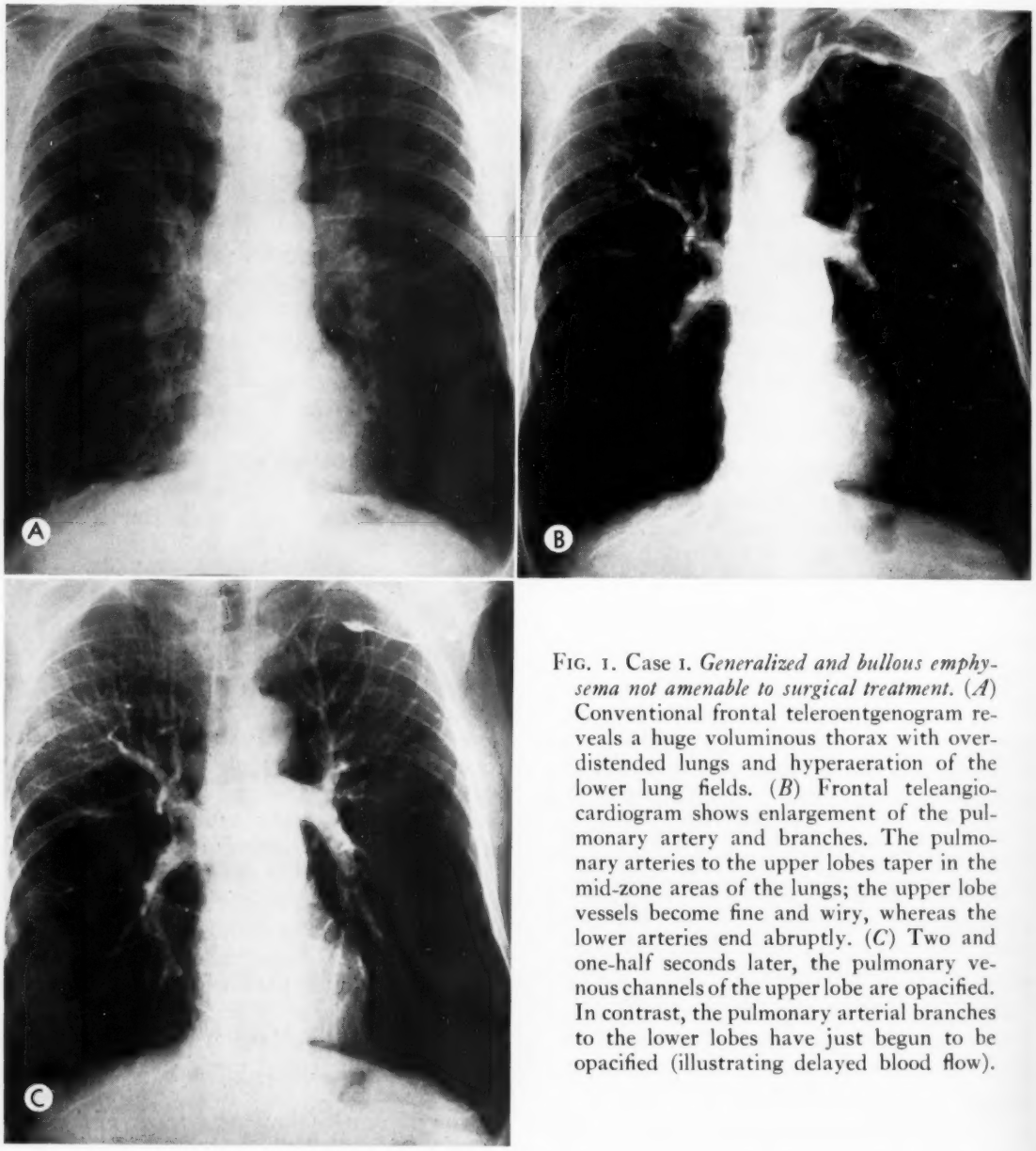

FIG. 1. Case 1. *Generalized and bullous emphysema not amenable to surgical treatment.* (*A*) Conventional frontal teleroentgenogram reveals a huge voluminous thorax with overdistended lungs and hyperaeration of the lower lung fields. (*B*) Frontal teleangiocardiogram shows enlargement of the pulmonary artery and branches. The pulmonary arteries to the upper lobes taper in the mid-zone areas of the lungs; the upper lobe vessels become fine and wiry, whereas the lower arteries end abruptly. (*C*) Two and one-half seconds later, the pulmonary venous channels of the upper lobe are opacified. In contrast, the pulmonary arterial branches to the lower lobes have just begun to be opacified (illustrating delayed blood flow).

there was pulmonary venous filling of the upper lobes, whereas the pulmonary circulation to the lower lobes had only reached the mid-zones of the lungs. Pulmonary function studies, four years prior to admission, had showed the vital capacity to be 3,600 cc. Three years later it had been only 1,400 cc.; prior to admission it was 2,100 cc.

The patient died seventeen days after entry (April 20, 1955) and at autopsy the lungs were tough, leathery, and of fibrous consistency, especially the lower lobes. Numerous small blebs were scattered over the entire surface of both lungs. Only small bullae of the lower lobes, measuring up to 5 cm. in diameter, were present. The cut surfaces of the lower lobes and the peripheral and apical portions of the upper lobes had a coarse spongy texture. There was moderate generalized emphysema and fibrous thickening of the alveolar walls. The bronchi were dilated and the elastic and muscular elements were largely replaced with fibrous tissue. There was marked fibrous thickening of the smaller arteries and the lumina of many were plugged

with organized thrombi. The diagnosis was bronchiectasis, generalized and bullous emphysema and pulmonary fibrosis. The heart showed the characteristic findings of cor pulmonale; the right ventricular wall measured 9 mm.

Comment. Clinically the patient had all the features of pulmonary emphysema. The conventional roentgenogram also showed cor pulmonale while the angiocardiogram showed the classic signs of generalized emphysema but without bullae. The serious and progressive character of the emphysema was also indicated by the pulmonary function studies.

Case II. *Generalized and bullous emphysema also unsuitable for surgery.* A sixty-six year old butcher (N.Y.H. No. 431550) had had frequent upper respiratory infections. For five years there had been a chronic cough with thick, tenacious, stringy sputum. Dyspnea on exertion followed so that shaving or eating caused attacks. On examination the patient was thin, afebrile, and chronically ill. Slight cyanosis of the lips and nailbeds was present; the respirations were rapid and shallow. The chest was asymmetric with a markedly increased anteroposterior diameter. Percussion was hyper-resonant with almost absent breath sounds in the left chest. The pulse rate was 90 and the blood pressure 200/110 mm Hg. The conventional frontal roentgenogram of the chest (Fig. 2*A*) showed a voluminous thorax with flattening of the diaphragms. An angiocardiogram (Fig. 2*B*) showed moderate enlargement of the pulmonary artery and branches, while the pulmonary arterial tree ended abruptly in the mid-zones of the lungs. The vascular pattern was interpreted as being typical of generalized emphysema except for a single large bulla at the left base. Pulmonary function studies showed the vital capacity to be only 1,400 cc.

Comment. This case illustrates the characteristic angiocardiographic features of advanced generalized pulmonary emphysema.

Case III. *Bilateral bullous emphysema; improved by right upper lobectomy.* A fifty-four year old man (N.Y.H. No. 643952) had had a fifteen

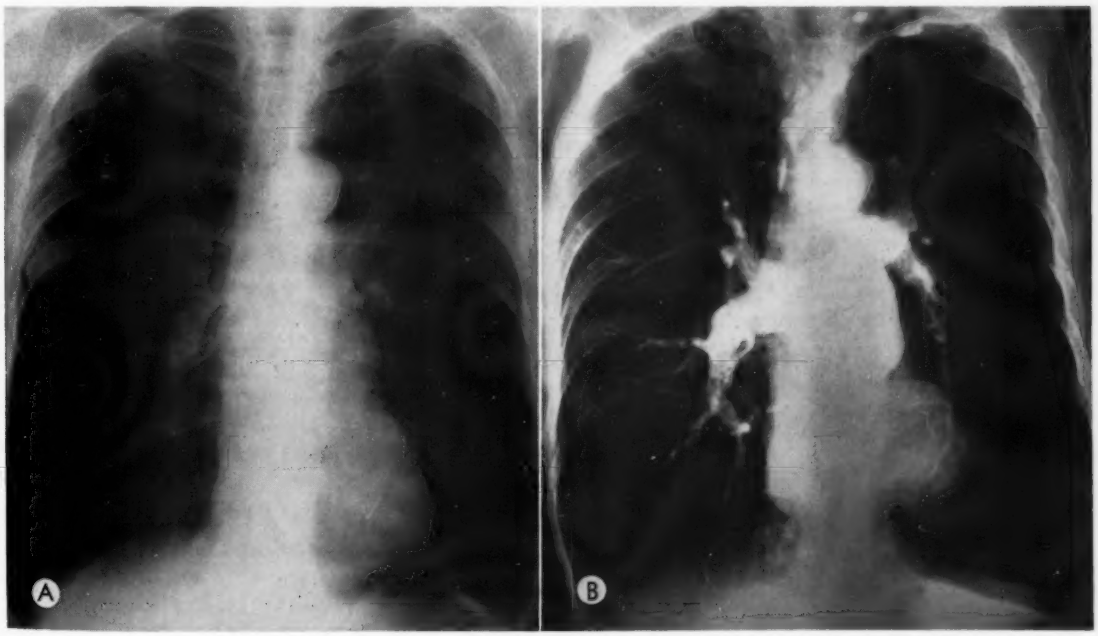

Fig. 2. Case II. *Generalized and bullous emphysema also unsuited for surgery.* (*A*) Conventional frontal roentgenogram reveals a voluminous thorax with increased translucency of the lungs, especially the bases. The pulmonary artery segment is prominent. (*B*) Frontal angiocardiogram shows enlargement of the pulmonary artery and branches. There is marked decrease in the pulmonary arterial tree, especially of the left lung. The right lung shows the wiry ("winter tree") pattern of generalized emphysema. The left lung shows the abrupt termination of the pulmonary arterial tree due to bullous emphysema.

year history of cough with profuse expectoration. Previously he had had pneumonia and bronchiectasis of the left lower lobe. For two years there had been increased dyspnea with drenching night sweats and loss of twenty pounds. He was able to climb only one flight of stairs. On examination the patient was thin, pale and chronically ill but there was no cyanosis or edema of the ankles. There was hyperresonance on percussion of the chest while the breath sounds were diminished, with wheezes over the entire thorax. The conventional frontal roentgenogram of the chest showed a voluminous thorax with increased radiolucency of the upper lung fields (Fig. 3*A*). An angiocardiogram (Fig. 3*B*) showed the pulmonary artery and branches to be moderately enlarged. The pulmonary vasculature of the upper lobes narrowed abruptly just beyond the hilus. The midzone pulmonary arterial branches were markedly decreased in number and caliber and were distorted, especially on the right side. The pulmonary vasculature of the lower lobes appeared displaced downward, more on the right than the left side, but were of normal caliber in the mid- and outer zones.

The arterial O_2 saturation was 90 per cent (predicted value 97 per cent). The pulmonary artery pressure was 31/14 mm. Hg at rest and 57/23 after exercise. The pulmonary vascular resistance in dynes per sec. cm.^{3} was 332 (normal 100). Pulmonary function studies revealed vital capacity of 2,754 cc. (predicted value 3,803 cc.). The residual volume-total lung capacity ratio was 57 per cent (predicted 31 per cent). The maximum breathing capacity (in liters per minute) was 25 (predicted value 94). The index of intrapulmonary mixing alveolar N_2 was 9.7 per cent (predicted value 2.5 per cent). The dead space-tidal volume ratio was 45 per cent (predicted value 30 per cent).

A right upper lobectomy with a pleural tent was performed on December 15, 1952. At operation, the right upper lobe was large and cystic and was devoid of normal pulmonary tissue. The right middle and lower lobes had minimal emphysematous changes. On pathologic section at least one half of the right upper lobe consisted of a soft, cystic, almost structureless mass which appeared to be totally composed of air filled spaces with a thin membranous capsule. Microscopically, there was moderate intimal thickening of the large arteries. The alveoli were dilated with some interalveolar fibrosis. The diagnosis was emphysema and fibrosis with arteriosclerosis of the pulmonary arteries.

Four months later, the conventional frontal roentgenogram of the chest (Fig. 3*C*) revealed some deviation of the trachea to the right and a dense right apex due to a pleural tent. The right lung appeared uniformly well aerated while the left upper lung field was overdistended with increased radiolucency.

Comment. Angiocardiographic studies in this case demonstrated bullae in both upper lobes with distortion and compression of the vasculature of the lower lobes but without the pattern of generalized emphysema. These findings with the clinical and functional studies of the lung predicted that surgery would be beneficial, and so it proved. The patient returned to work; seven years later he was well despite the remaining left upper lobe bulla.

CASE IV. *Bilateral bullous emphysema; improved by bilateral upper lobectomy.* A fifty-six year old man (N.Y.H. No. 541430) was examined on June 12, 1949, because of severe dyspnea of three years' duration. During the previous six months he had had a chronic, persistent and productive cough. On physical examination the posteroanterior diameter of the chest was markedly increased and there were inspiratory and expiratory rales over both upper lobes. The conventional frontal roentgenogram of the chest showed marked radiolucency in the upper halves of the lung fields (Fig. 4*A*). Angiocardiograms on May 19, 1949, revealed compression of the lower lung field vasculature with markedly decreased vasculature of the upper lungs (Fig. 4*B*). At operation on June 17, 1949, the left upper lobe was completely replaced by several large bullae which compressed and displaced the lower lobe into the inferior portion of the thoracic cage. Left upper lobectomy was performed. A large bulla was excised from the apical segment of the lower lobe and a pleural tent made. Pathologic study of the left upper lobe showed multiple bullae varying from 1.5 to 9 cm. in diameter. Microscopically, the cyst walls consisted of collagenous connective tissue lined in some areas by cuboidal epithelium. The adjacent lung parenchyma had dense bands of fibrous tissue traversing it. The final diagnosis was bullous emphysema and fibrosis.

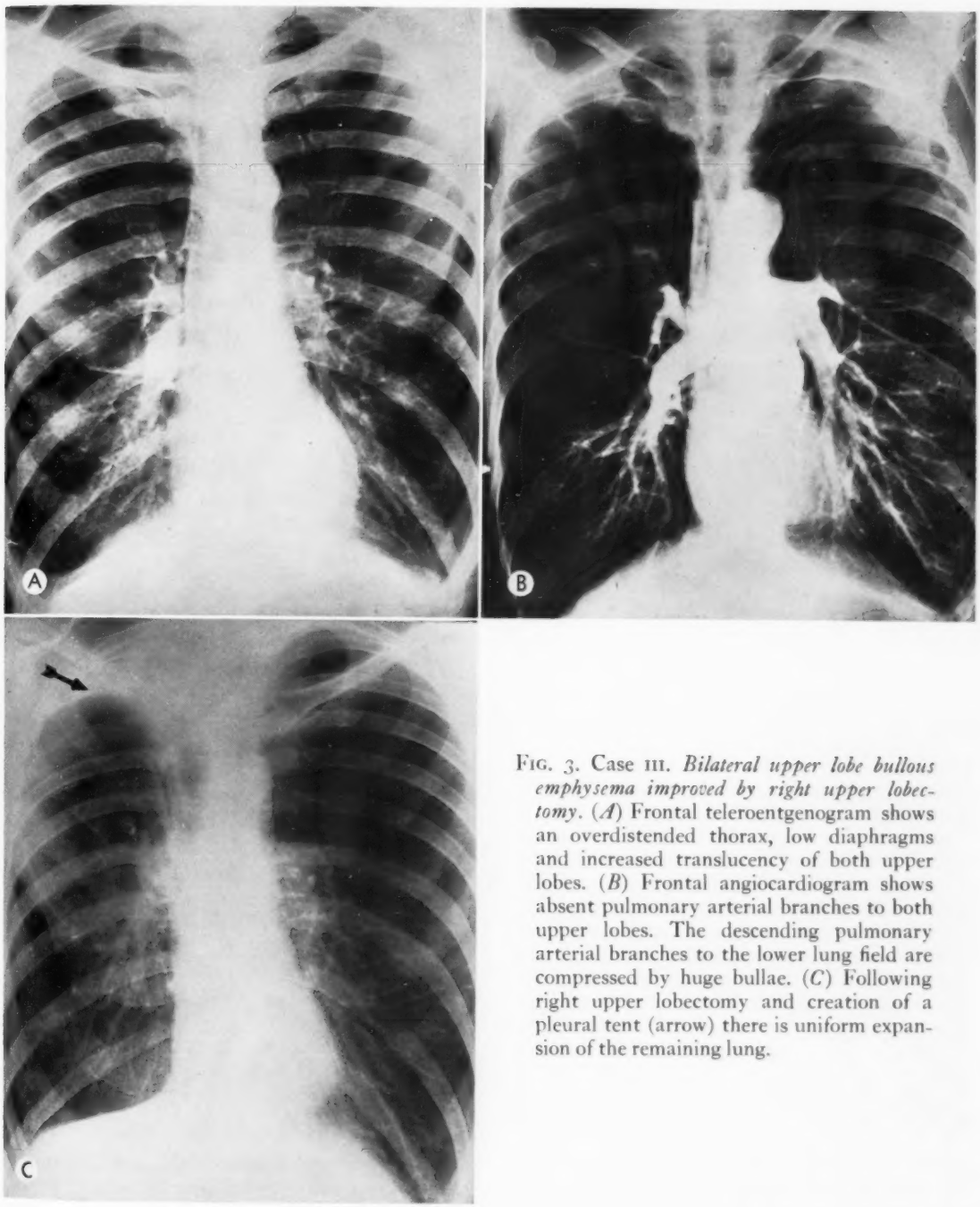

Fig. 3. Case III. *Bilateral upper lobe bullous emphysema improved by right upper lobectomy.* (*A*) Frontal teleroentgenogram shows an overdistended thorax, low diaphragms and increased translucency of both upper lobes. (*B*) Frontal angiocardiogram shows absent pulmonary arterial branches to both upper lobes. The descending pulmonary arterial branches to the lower lung field are compressed by huge bullae. (*C*) Following right upper lobectomy and creation of a pleural tent (arrow) there is uniform expansion of the remaining lung.

Postoperative angiocardiograms (March 9, 1950) showed the density at the left apex due to the pleural tent (Fig. 4*C*). There was increased radiolucency at the left base and marked radiolucency in the upper two-thirds of the right lung with compression and displacement of the vasculature into the lower portion. The pulmonary vessels of the left lung appeared uniformly distributed, decreased in number and caliber.

For four years the patient was well and able to do regular work but gradually became totally disabled because of dyspnea. On April 12, 1954, a right upper lobectomy was performed. Pathologic study revealed the pleural surface to be

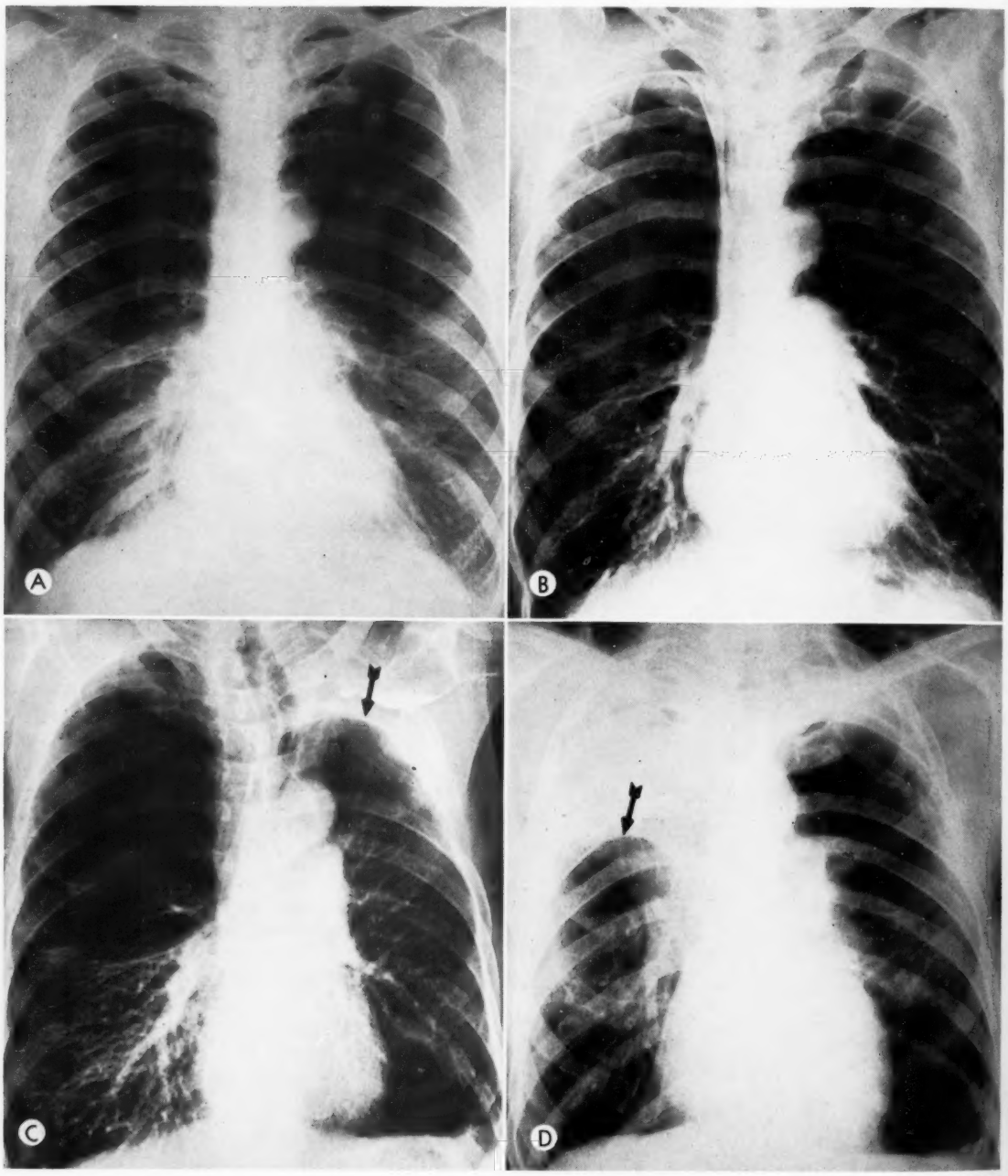

FIG. 4. Case IV. *Bullous emphysema improved by bilateral upper lobectomy.* (*A*) Conventional frontal roentgenogram shows huge bilateral bullae of both upper lung fields with compression of the lower lung fields. (*B*) Angiocardiogram shows absence of pulmonary arterial circulation of the upper lobes with marked compression of the pulmonary vasculature of the lower lobes. (*C*) Following left upper lobectomy and formation of a pleural tent (arrow), the left pulmonary arterial tree was no longer compressed. Note the appearance of a large left lower lobe bulla. Despite this, clinical improvement resulted. (*D*) Four years later, recurring dyspnea necessitated a right upper lobectomy and pleural tent formation (arrow). This was followed by improvement and return to work, now of five years' duration.

thickened and with many large bullae. The cut surface had a honeycomb appearance involving one half of the specimen. Marked peribronchial inflammatory infiltration was seen. The final diagnosis was bullous emphysema, bronchiectasis and compensatory atelectasis.

The postoperative conventional frontal roentgenogram of the chest taken on June 17, 1954, disclosed good aeration of the right lung, although a radiolucency at the left base was still noted (Fig. 4*D*). Following this the patient resumed his regular work but died five years later (1959) of emphysema and cor pulmonale.

Comment. Angiocardiography by revealing bilateral upper lobe bullous emphysema without evidence of generalized emphysema strengthened the decision to perform surgery on 2 separate occasions and eventually restored the patient's ability to work for several years.

Case v. *Bilateral bullous emphysema; right pneumothorax cured after excision of bullae and blebs.* A thirty-eight year old woman (N.Y.H. No. 679045) came to the clinic on March 22, 1954, with a history of a previous spontaneous left pneumothorax. On examination the chest was asymmetric and expanded equally. The breath sounds were distant and the lung fields were uniformly resonant. Roentgenoscopy revealed a large cyst in the upper third of the right chest which increased in size on deep inspiration and decreased with expiration. Another large cyst in the lower half of the left chest was unaltered by respiration. Review of previous roentgenograms beginning in 1944 showed a progressively enlarging cyst at the left base, whereas the cyst in the right upper lung field had been unchanged in size during a ten year period. Angiocardiography (Fig. 5*A*) on May 4, 1954, showed a huge cyst occupying the lower two-thirds of the left lung which distorted and compressed the left lower pulmonary vasculature. A smaller cyst was also present in the upper third of the right lung. The pulmonary vasculature appeared sparse in the upper lobes. Pulmonary function data revealed the vital capacity to be 2,291 cc. (predicted value 2,810 cc.). The maximum breathing capacity in liters per minute was 98 (predicted value 83).

Surgery on the left side was advised but refused by the patient. She was re-admitted on June 26, 1956, with complaints of mild dyspnea on exertion and a chronic nonproductive cough of one year's duration. Just prior to admission

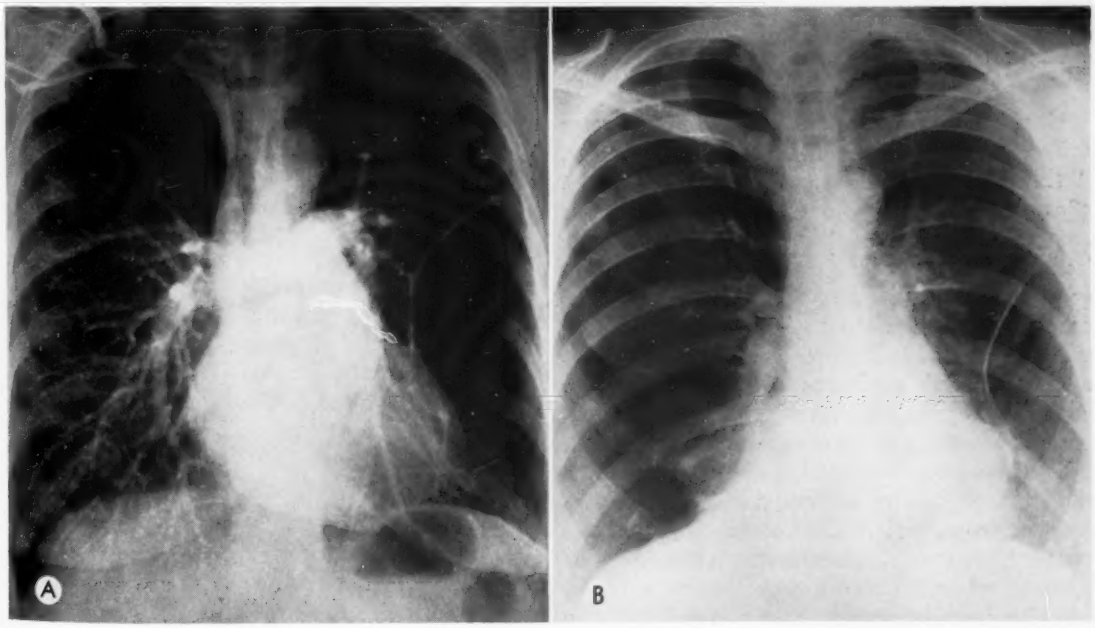

Fig. 5. Case v. *Bilateral bullous emphysema complicated by right spontaneous pneumothorax that failed to re-expand following suction.* (*A*) Frontal angiocardiogram shows bullous emphysema of both lungs causing classic compression of the remaining lung. (*B*) Two years later, a right spontaneous pneumothorax failed to re-expand after suction; excision of cysts restored pulmonary function.

the dyspnea suddenly became worse and there was chest pain. A frontal chest roentgenogram revealed 70 per cent pneumothorax on the right (Fig. 5*B*). Intercostal tube drainage failed to reduce the pneumothorax and so surgical treatment was advised. At thoracotomy, there was a liter of serous fluid in the right chest; a 10×4 cm. bulla was found in the apical segment of the upper lobe. The pleural surface of all lobes of the lung was studded with multiple (2–3 mm.) emphysematous blebs while on the inferior border of the middle lobe there were several large (2 cm.) blebs. A 6×5 cm. bleb was also present in the lateral basal segment of the lower lobe. Many blebs were excised; others were transfixed and covered with pleural grafts. Following this the patient made an uneventful recovery. On re-examination a year later, dyspnea was no longer present although the left lower lobe cyst remained.

Comment. This case illustrates a common complication of bullous emphysema—spontaneous pneumothorax. The enlarging cyst in the left lung and the symptomatic state of the patient warranted surgical intervention when she was first seen. Later, the spontaneous pneumothorax on the opposite side with failure to secure re-expansion after suction drainage made surgery necessary in the right side.

CASE VI. *Generalized and bullous emphysema; failure to improve following left lower lobectomy.* A thirty-nine year old housewife (N.Y.H. No. 389560) had had dyspnea and a productive cough for seven years. Six years previously she had been admitted to another hospital for a spontaneous right hydropneumothorax. Recently, the cough had been productive of one cup of greenish sputum daily. Physical examination showed moderate respiratory distress with difficulty in expiration. There was no cyanosis or edema. The anteroposterior diameter of the thorax was increased and the respiratory rate was rapid with increased use of accessory muscles of respiration. The diaphragms were low; the breath sounds were distant and a few inspiratory rales were present at both bases. The chest was hyper-resonant throughout. The conventional frontal roentgenogram of the chest showed markedly distended lungs with extremely low diaphragms and increased radiolucency of the lower lung fields (Fig. 6*A*).

Angiocardiograms (Fig. 6*B*) made on March 2, 1953, showed moderate enlargement of the pulmonary artery and main branches. The pulmonary vascular tree appeared wiry. In the lower lobes the pulmonary arterial vasculature appeared diminished. There was slight distortion and compression of the peripheral vascular pattern in the left lower lung field (Fig. 6*B*). Pulmonary function studies were done January 17, 1950, and revealed the vital capacity to be 2,800 cc. (predicted value 3,286 cc.), while the maximum breathing capacity in liters per minute was 56 (predicted value 92). On April 8, 1953, the vital capacity was 1,553 cc. and the maximum breathing capacity was 34. The O_2 saturation was 91.8 per cent (predicted value 97 per cent). After exercise the O_2 saturation was 85.7 per cent. The CO_2 tension was normal at rest and exercise. On December 3, 1953, the vital capacity was 1,253 cc. and the maximum breathing capacity was 22.

At operation, April 5, 1954, the left lower lobe was distended and compressed the left upper lobe into a third of its normal volume. Some emphysematous changes were visible in the left upper lobe, particularly along the lower borders and in the lingula. Left lower lobectomy was performed and a pleural tent was made. On pathologic section, bullae were most prominent in the posterior and medial aspect of the left lower lobe. The lung tissue occupying the lower half of the lobe was very emphysematous and spongy in appearance. Fifteen days following operation congestive failure developed. Figure 6*C* is the postoperative roentgenogram. Severe dyspnea persisted and pulmonary function studies on May 23, 1955, revealed the maximum breathing capacity to be only 19. The O_2 saturation at rest was 89 per cent; with mild exercise it was 85 per cent. The patient continued to be dyspneic, developed right sided heart failure, fever, and died on December 13, 1955.

Autopsy showed marked generalized emphysema of the right lung. The largest bulla was only 5 mm. in diameter. However, on the left, the lowermost portion of the upper lobe contained many large bullae. One measured 6×3×3 cm. and another 6×6×8 cm. The remainder of the left upper lobe was sponge-like in consistency; the largest bulla in the upper portion of the lobe was 4 mm. in diameter. Microscopically, the alveolar walls were slightly thickened; a few alveoli contained hemosiderin-filled macrophages. The basement membranes

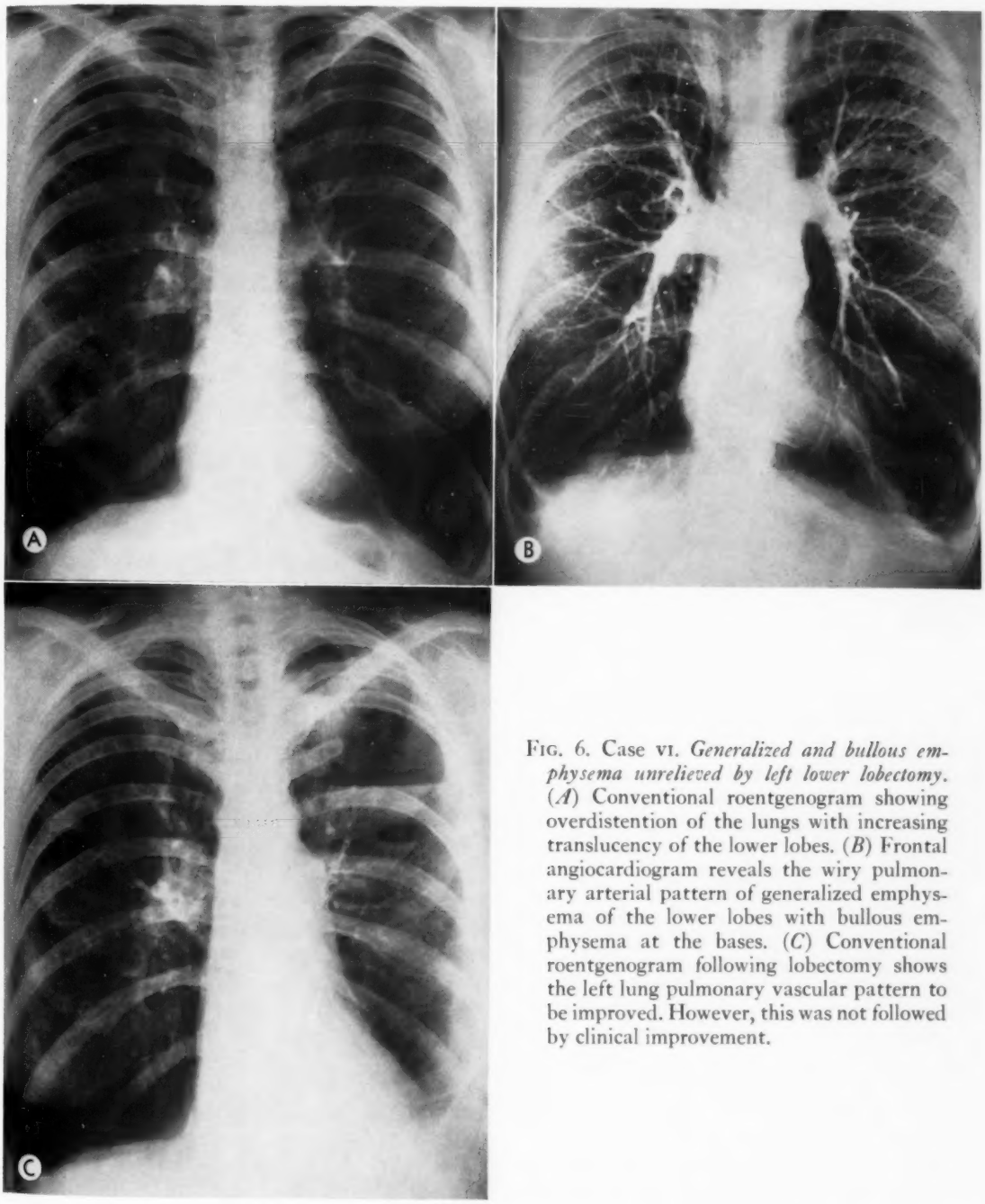

Fig. 6. Case vi. *Generalized and bullous emphysema unrelieved by left lower lobectomy.* (*A*) Conventional roentgenogram showing overdistention of the lungs with increasing translucency of the lower lobes. (*B*) Frontal angiocardiogram reveals the wiry pulmonary arterial pattern of generalized emphysema of the lower lobes with bullous emphysema at the bases. (*C*) Conventional roentgenogram following lobectomy shows the left lung pulmonary vascular pattern to be improved. However, this was not followed by clinical improvement.

of the bronchioles were thickened. There was evidence of acute and chronic bronchitis in the right middle and lower lobes. The small arteries were slightly thickened throughout and there was considerable atherosclerosis. The diagnosis was advanced generalized pulmonary emphysema in all lobes of the lungs with bullous emphysema in the lower portion of the left upper lobe. The heart weighed 458 gm. and there was marked right sided hypertrophy and dilatation. A ruptured diverticulum and generalized peritonitis were the immediate causes of death.

Comment. The degree of functional deficit demonstrated by the physiologic data

correlated with the localized nature of the bullae and the signs of generalized emphysema visualized on the angiocardiograms accurately predicted that little improvement could be expected after surgery. Although the localized bullous emphysema in the left lower lobe was removed surgically, the relentless progress of the generalized emphysema was eventually fatal.

CASE VII. *Bullous emphysema of the entire right lung improved by pneumonectomy.* A sixty-six year old man (N.Y.H. No. 793691) was admitted April 23, 1958, with a history of dyspnea of ten years' duration. Twenty years prior to admission he had had a right spontaneous pneumothorax which was treated by repeated needle aspirations. One week prior to admission there were expectoration of blood and pain in the right chest. On physical examination the anteroposterior diameter of the thorax was increased. There was dullness over the right posterior upper chest, and decreased breath sounds with occasional expiratory wheezes were heard over the entire right chest; the respiratory rate was rapid. The pulse rate was regular, rate 94, and the blood pressure was 210/100 mm. Hg; the heart was not enlarged. The conventional frontal roentgenogram of the chest (Fig. 7*A*) showed overdistention of the right lung with downward displacement and flattening of the right diaphragm. There were large cysts in the right lung and extensive fibrosis in the right lower lung fields. Frontal laminagrams of the chest clearly showed the large cysts of the right lung (Fig. 7*B*). Lateral laminagrams also showed that the large cysts occupied almost the entire right lung (Fig. 7*C*). Serial angiocardiograms (Fig. 7*D*) on April 24, 1958, showed abrupt termination of the pulmonary arterial vasculature at the right hilus. The left pulmonary artery was well visualized and the peripheral circulation appeared decreased.

On April 28, 1958, a right pneumonectomy was performed. The major portion of the entire right lung contained bullae varying from 1 to 10 cm. in diameter. One large cyst dissected between the bronchus and the right pulmonary artery had almost completely shut off the circulation to the right lung. Bullae also extended into the mediastinum where they compressed and displaced the esophagus. On pathologic section, the right lung appeared markedly lobulated with many bullae and blebs over the entire surface. There was extensive pleural thickening. Microscopically, the pulmonary arterial walls were thickened. The alveolar walls were thin and the alveoli were distended in many areas. The diagnosis was extensive bullous emphysema and interstitial fibrosis. The patient has remained well for two years.

Comment. Laminagraphy showed the changes of advanced bullous emphysema in the right lung to advantage, whereas angiocardiography revealed almost complete obstruction of blood flow to the right lung due to compression of the right pulmonary artery by bullae. These studies accurately foretold the benefit of pneumonectomy.

CASE VIII. *Bilateral bullous emphysema with spontaneous left pneumothorax; improved by segmental resection.* A fifty-nine year old man (N.Y.H. No. 657937) had had sudden onset of severe dyspnea and pain in the left chest six days prior to admission in December, 1955. On physical examination, the chest was symmetric and the left chest was hyper-resonant. The breath sounds in the left upper anterior chest were increased but were decreased throughout the remainder of the left chest. The pulse rate was 70 and regular and the blood pressure was 180/90 mm. Hg. Conventional roentgenograms of the chest showed a 50 per cent pneumothorax in the left lung in addition to large cysts in both upper lobes. Two years earlier (1953) the conventional frontal roentgenogram of the chest showed large cysts occupying the upper one-third of both lungs (Fig. 8*A*). Angiocardiograms at that time (June 12, 1953) revealed the entire right pulmonary arterial tree to be compressed into the lower two-thirds of the chest (Fig. 8*B*). The vasculature of the upper one-third of the left lung was also compressed laterally. Other angiocardiographic studies on December 6, 1955 (Fig. 8*C*) showed a left pneumothorax with almost complete collapse of the left lower lobe. The left upper lobe vasculature appeared compressed laterally to a greater extent than on the previous study, whereas the vasculature in the right chest appeared unchanged in the two year interval.

Pulmonary function studies on December 7, 1955, revealed the vital capacity to be 3,010 cc. (predicted value 3,635 cc.). The maximum breathing capacity was 65 (predicted value

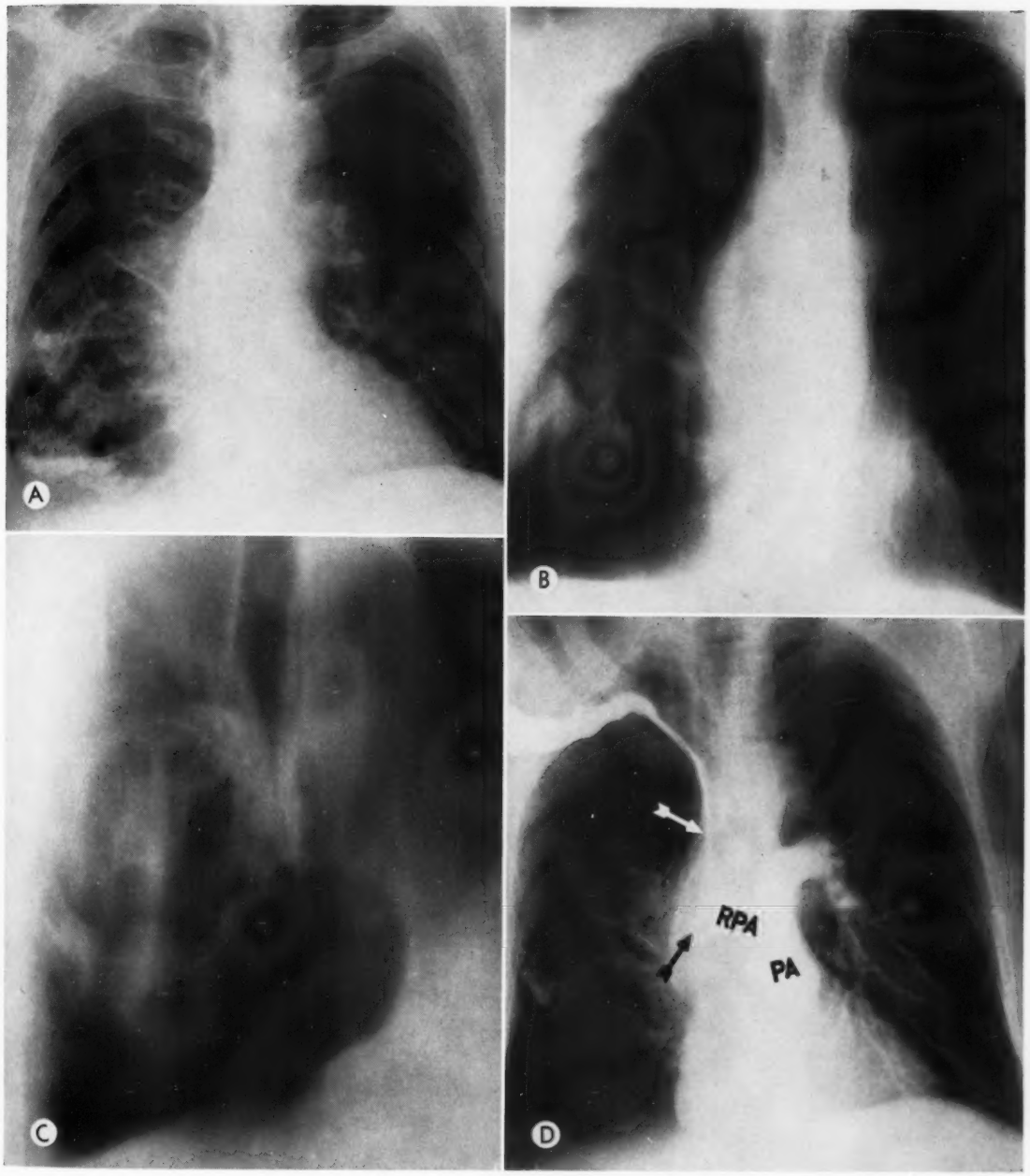

Fig. 7. Case VII. *Bullous emphysema of the right lung, improved by pneumonectomy.* (*A*) Frontal roentgenogram shows multiple bullae of the right lung, especially at the base. (*B*) Frontal laminagram shows numerous cysts in the right lower lobe. (*C*) Right lateral laminagram reveals the size of the bullae. (*D*) Frontal angiocardiogram shows narrowing of the superior vena cava (arrow) and absence of right pulmonary arterial blood flow (arrow). PA is the pulmonary artery and RPA is the right pulmonary artery.

103). At operation on December 12, 1955, a tension pneumothorax was present and there was marked overdistention of the apicoposterior segment of the left upper lobe due to numerous large bullae. A segmental resection was done and a pleural tent formed. In the remaining lung there were three small blebs. On pathologic study many blebs measuring 2–3 cm. in diameter were present on one margin of the lung segment. There was marked fibrous thickening around some of the bronchioles and along the alveolar walls. The pleura was also thick-

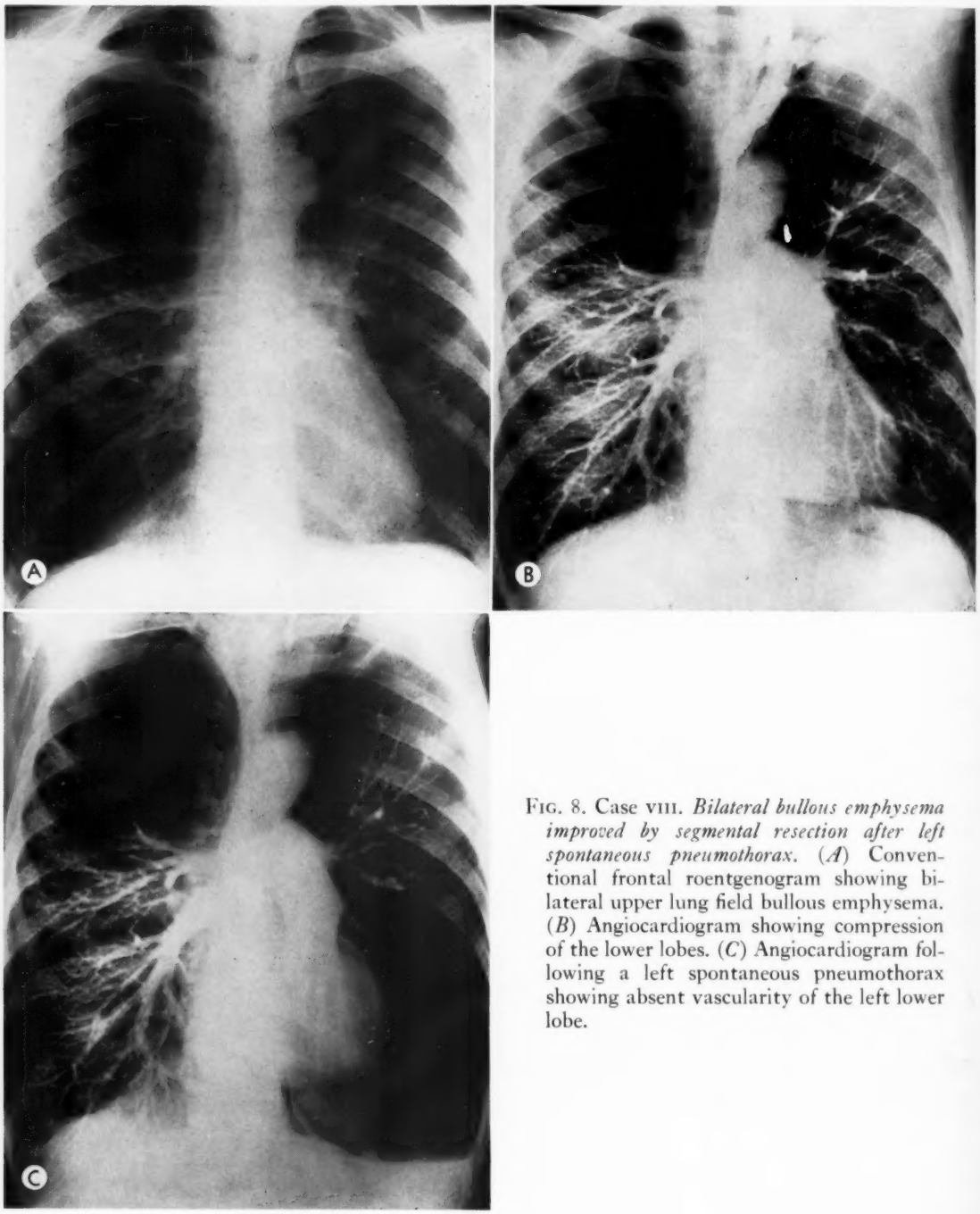

FIG. 8. Case VIII. *Bilateral bullous emphysema improved by segmental resection after left spontaneous pneumothorax.* (*A*) Conventional frontal roentgenogram showing bilateral upper lung field bullous emphysema. (*B*) Angiocardiogram showing compression of the lower lobes. (*C*) Angiocardiogram following a left spontaneous pneumothorax showing absent vascularity of the left lower lobe.

ened. The diagnosis was bullous emphysema and fibrosis.

Postoperative frontal roentgenograms of the chest showed a re-expanded left lung with a pleural tent at the apex. There was a 4×3 cm. cyst just beneath the pleural tent. The cyst in the right upper lung field appeared much smaller than on previous studies (Fig. 8*D*). Repeat angiocardiograms on April 18, 1957 (Fig. 8*E*) showed a moderately enlarged pulmonary artery and branches. The sparse right upper lobe vasculature was compressed laterally but to a much lesser extent than in the previous studies. A cyst just below the left pleural tent

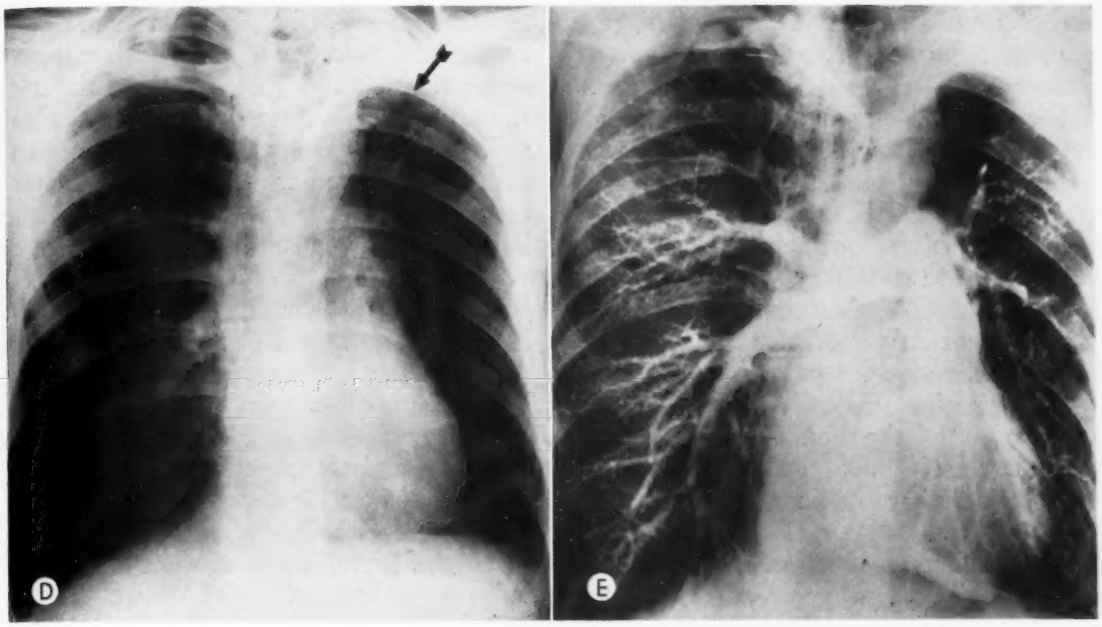

Fig. 8. Case VIII. (*D*) Improvement followed segmental resection of the left lung and formation of a pleural tent (arrow). (*E*) Angiocardiogram following operation shows return of the normal pulmonary arterial pattern in the left lung.

was also seen. Following operation the patient became asymptomatic and resumed work.

Comment. Although angiocardiography indicated that the bullous emphysema was more extensive on the right side, spontaneous pneumothorax on the left side necessitated surgical intervention. Spontaneous improvement in the right lung made further surgery unnecessary.

DISCUSSION

Bullae (pneumatoceles) are hyperinflated intrapulmonary cavities produced by the marked distention of a defect in the pulmonary parenchyma.[7,14] Blebs are similar to bullae except that they are subpleural rather than intraparenchymal; both have indirect bronchial communication and physiologically exhibit air trapping.[16] Pulmonary cysts are congenital in origin, are lined by cuboidal or columnar epithelium and have frank bronchial communications which are frequently partially filled with fluid.

The etiology of pulmonary emphysema is not as yet completely defined. It is generally agreed that the primary lesion is one of bronchiolar obstruction with subsequent air-trapping distal to the obstruction. There is loss of pulmonary elasticity and finally there is disruption of the alveolar walls with bulla formation. The cause of the obstructive phenomena is attributed to a variety of histopathologic changes. Amberson and Spain,[1] and Spain and Kaufman[27] have surmised that chronic bronchiolitis and peribronchiolitis involving terminal bronchioles result in stiffening of the walls and narrowing of the lumina. The inflammation and subsequent fibrosis involve the musculature and elastic components and interfere with the tone and action of the involved bronchiolar walls. Inspiration tends to expand the narrowed bronchioles allowing passage of air into the respiratory alveoles and alveoli. On expiration, however, the caliber of the narrowed bronchioles is further reduced and delays emptying of the alveoli of the involved lobules. This check-valve mechanism tends to dilate alveoli. Because the chronically distended alveoli receive a diminished blood and oxygen supply,

atrophy and disruption occur.[12] The presence of tenacious mucus in the bronchial passages also aggravates the mechanism.

McLean[15] proposed that obstruction of small bronchioles with mucous plugs occurs in acute bronchiolitis. If obstruction persists there may eventually be obliteration of the bronchiole, particularly in the proximal order of respiratory bronchioles. During the phase of obstruction there is collateral ventilation of the distal alveoli through the alveolar pores of Cohn. During inspiration there is good collateral ventilation of the alveoli in the regions distal to the obstruction while in expiration the channels become narrow and tortuous and cause some degree of air trapping. Recurrent infections with subsequent bronchiolar obliteration promote and potentiate air trapping with its associated alveolar distention. There is then reduced blood flow in the capillaries of the collaterally ventilated alveolar walls due to distention of the alveoli by the increased pressure of the trapped air. With decreased blood flow, there are decreased oxygen supply and nutritive factors with subsequent loss of elasticity and atrophy of the alveolar walls. The alveolar pores of Cohn increase in size at the expense of the wall and are reduced in thickness. As the process continues many of the septa break and a large bulla is formed.[12] The most severe emphysematous changes are seen in sites where collateral ventilation is restricted by tissue impervious to air, near the pleura or scar tissue.

Peirce and Dirkse[20] in 1937 described the development of pneumatoceles as complications of lobar or lobular pneumonia. They postulated a persistent check-valve effect in the bronchus due to nonresolution of the initial inflammation of the bronchus or a subsequent distortion by the dilated air spaces. In only one of their 4 cases did the pneumatoceles disappear despite almost complete clearing of the surrounding parenchymal infiltrations. Other obstructive factors have also been proposed to explain special instances of localized emphysema. Shaw[25] noted that the bronchi of the affected lobes were abnormally flaccid and suggested that localized chondromalacia of the bronchus results in expiratory bronchial collapse with obstructive emphysema distal to the block. Ferguson and Neuhauser[9] described absent cartilaginous rings in the left main bronchus of 2 cases with emphysema of a whole lung. Robertson and James[22] reported a case wherein a large vein hooked around the right upper lobe bronchus resulting in narrowing of the bronchial lumen. In another case, valve-like mucosal flaps were present in the right upper lobe bronchus and were considered responsible for the obstructive distention of the lobe. The role of chronic bronchiectasis, asthma, attacks of bronchiolitis and pneumonitis in bullous emphysema is well known and has long been stressed.[4]

History and physical examinations in association with chest roentgenograms are important for evaluation of pulmonary emphysema. Roentgenoscopy of the chest also should be performed to estimate diaphragmatic, mediastinal and thoracic cage mobility. Changes in radiolucency of special areas of the lung during respiration should be surveyed to evaluate the degree of air trapping in bullae. The amount of compression of surrounding lung parenchyma by bullae should also be noted. Bronchoscopy in selected patients with emphysema helps to rule out foreign bodies or endobronchial lesions. Bronchography is hazardous, especially when there is severe dyspnea. It is sometimes helpful in differentiating cystic bronchiectasis, congenital pulmonary cysts[3] and abnormal transradiancy of one lung[13] from bullous emphysema. Laminagraphy has also been useful for locating bullae (Fig. 7, *B* and *C*).

Cardiopulmonary and bronchospirometric studies have provided physiologic data for clarifying functional deficits in patients with emphysema. The arterial O_2 saturation, the degree of CO_2 retention, the maximum breathing capacity, the alveolar index and the residual volume to lung capacity ratio are all helpful data. In bullous

emphysema relative hypoventilation of some compressed normal parenchyma, although well perfused, causes elevated venous admixture ratios which augment hypoxia and hypercapnia. Abnormal ventilation perfusion relationships in both generalized and localized bullous emphysema with lung compression can produce hypoxia and even hypercapnia. A high residual volume, poor alveolar mixing and a decreased maximum breathing capacity could be due to bullae communicating with the lung, a high degree of air trapping, to bullae compressing normal adjacent parenchyma and obstructing ventilation, or to generalized emphysema. The specific differentiation of patients with localized bullous emphysema with compression of either relatively normal or emphysematous adjacent lung parenchyma from those with generalized pulmonary emphysema on the basis of physiologic data alone may be difficult.[2,3,10,11,26]

The patients with bullous emphysema who may be benefited by surgery may be classified into four groups: bullae with recurrent pneumothorax on one or both sides;[5,6] infected bullae (tuberculous or nontuberculous);[23,24] bullae increasing in size; and bullae with progressive symptoms of dyspnea, chest pain, cough and sputum. Patients in the first three groups can be frequently found to be suitable for surgery without the need of angiocardiographic study. In the fourth group, the basic problem is how to differentiate the patients whose symptoms are due to bullous emphysema from those with symptoms related primarily to generalized pulmonary emphysema.

Angiocardiography by outlining the pulmonary vasculature is useful for determining the degree of generalized and bullous types of emphysema. For example, in generalized emphysema (Fig. 1, *B* and *C;* and 2*B*) the characteristic "winter tree pattern" is evident. The pulmonary arterial branches taper abruptly in the midzone and continue in a wiry pattern causing delayed blood flow. Bullae (Fig. 3*B;* 4, *B* and *C;* 5*A;* and 8, *B*, *C* and *E*) are avascular and distort and compress the pulmonary arterial tree. The degree of functional impairment of the surrounding parenchyma can thus be judged. Combined generalized and bullous emphysema may be difficult to evaluate even with angiocardiography (Fig. 6*B*). The correlation of the patient's clinical status, pulmonary functional deficits, degree of bullous involvement and the extent of generalized emphysema seen angiocardiographically are the best criteria for selecting the patient suitable for surgery.

SUMMARY AND CONCLUSIONS

Eight patients with disabling emphysema were selected to illustrate the role of angiocardiography in the diagnosis and treatment of their disease. In generalized emphysema, the pulmonary vasculature resembles a "winter tree" pattern in that there is tapering and constriction of the peripheral pulmonary arterial tree. In bullous emphysema, there is diminution or absence of pulmonary vasculature because of the cysts. More important, though, is recognition of compression of the neighboring lung by the cysts. For it is reasonable to hope that the removal of useless portions of the lung will not only benefit pulmonary function but that the restoration of previously compressed pulmonary segments and lobes will improve it. Furthermore, if it can be proved that hypoxia and cor pulmonale are due to localized bullous emphysema, the indication for surgery is strengthened.

Angiocardiography by revealing the pulmonary vasculature readily discloses the patterns of generalized and bullous emphysema and also shows the state of the adjacent circulation. In a series of 8 cases, 2 patients had advanced generalized emphysema which overshadowed the bullous changes and contraindicated surgery. In 5 other patients with predominating bullous emphysema, even though bilateral, angiocardiography aided in evaluating the degree of compression caused by the pulmonary cysts. Surgical improvement fol-

lowed excision of cysts, segments, lobes and lung. In one case, though, excision of a left lower lobe bulla failed to halt the relentless progress of the generalized emphysema.

Various surgical procedures successfully employed in the treatment of 5 patients with bullous emphysema are discussed. These are transfixing blebs and covering with pleura, segmentectomy, lobectomy, and waiting for spontaneous regression of bullae. Dominant principles are the excision of as little normal lung tissue as possible and the prevention of overdistention of the lung by forming a pleural tent.

Although cardiopulmonary and bronchospirometric evaluation of patients provides physiologic data useful for clarifying functional deficits, it cannot always differentiate the patients who are symptomatic primarily due to bullous emphysema from those who are symptomatic due to general emphysema. It is precisely in such situations that angiocardiography becomes important, for, by visualizing the pulmonary circulation, the areas of generalized and bullous emphysema can readily be demonstrated. Furthermore, the effects of the air cysts on the neighboring circulation can be evaluated.

Accordingly, it is concluded that angiocardiography may be useful for the selection of the case likely to be helped by the removal of cysts and bullae. It is also valuable for assessing the improvement in the pulmonary circulation following surgery. Angiocardiography is obviously not necessary in order to decide that operation is needed by patients with bullae who have recurrent pneumothoraces, pulmonary and pleural infections or enlarging bullae.

Israel Steinberg, M.D.
The New York Hospital—Cornell Medical Center
525 East 68th Street
New York 21, New York

ADDENDUM

After completion of this study, two new papers dealing with the roentgen diagnosis of emphysema were published: Fraser, R. C., and Bates, D. V. Body section roentgenography in the evaluation and differentiation of chronic hypertrophic emphysema and asthma. AM. J. ROENTGENOL., RAD. THERAPY & NUCLEAR MED., 1959, *82*, 39–62 and Margolin, H. N., Rosenberg, L. S., Felson, B., and Baum, G. Idiopathic unilateral hyperlucent lung: a roentgenologic syndrome. AM. J. ROENTGENOL., RAD. THERAPY & NUCLEAR MED., 1959, *82*, 63–75.

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COLLATERAL VENTILATION AND LOCALIZED EMPHYSEMA*

By MORRIS M. CULINER, M.D., *and* STANLEY B. REICH, M.D.
SAN FRANCISCO, CALIFORNIA

LOCALIZED pulmonary emphysema presents a problem in the differential diagnosis of its pathogenesis. Awareness of the sequelae of segmental bronchial obstruction and the resultant regional collateral ventilation may simplify the problem. In this paper we shall not concern ourselves with the disease entity of generalized emphysema and its pathogenesis, but rather with localized emphysema in association with obstruction of a segmental or subsegmental bronchus. In 1931 Van Allen and Lindskog[8] demonstrated collateral ventilation in the experimental animal. Subsequently, with the development of the field of thoracic surgery, surgeons became familiar with the phenomenon of transsegmental filling of lung segments through collateral channels, despite the surgical occlusion of the segmental bronchi which normally would ventilate those specific segments. These collateral channels are communications through the interalveolar septa. They are frequently referred to as the pores of Kohn,[4] following his description of them in 1893. The presence of such openings, which permit the passage of gases from alveoli of one segment to those of adjacent segments, has been substantiated frequently in recent medical literature by Macklin,[6] Loosli,[5] and others. In contradistinction to the segments of the lobe, the total lobe is an isolated unit with essentially no collateral channel communications with adjacent lobes. Thus, total lobar bronchial obstruction is invariably followed by collapse of the lobe and absence of aeration.

Clinically, segmental bronchial occlusion may be followed by ventilation of that segment of lung tissue through collateral channels. By virtue of the abnormal mechanics of ventilation through the collateral conduits, emphysematous changes may occur in the lung thus filled. Air drift through the pores of Kohn occurs more readily during expansion of the lung than during contraction. With expansion of the thoracic cage and the lung within it, the pores of Kohn are widely patent. McLean[7] offers the hypothesis that the positive pressure of expiratory contraction of the chest wall and lung causes collapse of the pores of Kohn. In essence, there is a check-valve mechanism at each of these collateral pathways. Thus, localized obstructive emphysema may follow long continued aeration of a portion of lung through collateral channels. Finding this localized emphysema roentgenologically may provide the clue to the basic pathogenetic factor. This would not be detected on routine chest roentgenograms. Further roentgenologic and clinical studies are indicated.

In a previous report[3] we presented 3 clinical cases of localized emphysema secondary to segmental or subsegmental bronchial occlusion. In these cases developmental bronchial fluid-filled cystic abnormalities were shown to be the cause of bronchial occlusion. Churchill[2] has discussed the occasional finding of aerated lung tissue peripheral to bronchi or bronchioles which were replaced by scar tissue in a disease which he termed "obliterative bronchitis or bronchiolitis." McLean[7] has also discussed inflammatory bronchiolar obliteration in the pathogenesis of generalized emphysema.

At this time we wish to describe an *in vivo* experimental demonstration of collateral respiration and to report 2 clinical cases which showed the emphysematous end-result of collateral respiration.

* From the Departments of Surgery and Radiology, Mount Zion Hospital, San Francisco, California.

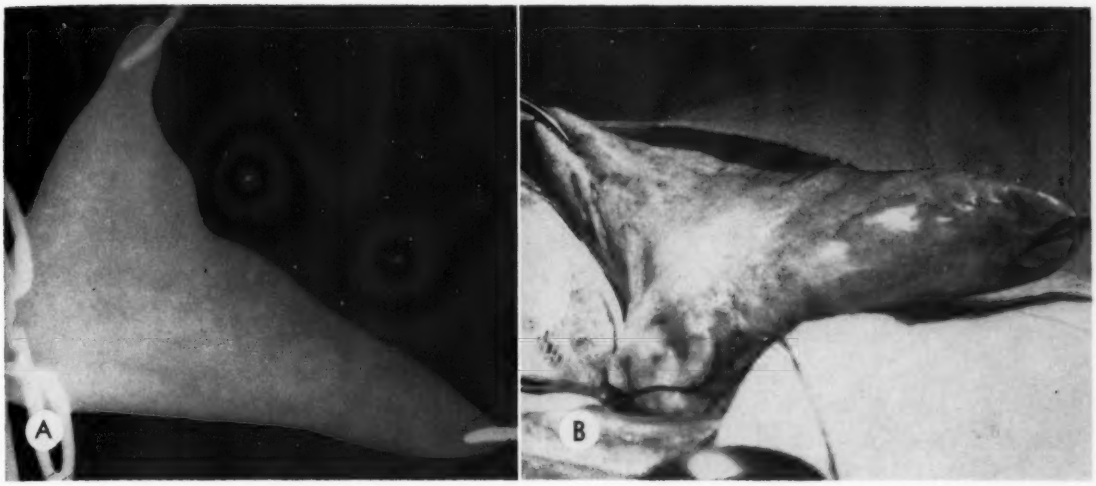

FIG. 1. Roentgenogram (*A*) and photograph (*B*) show total collapse and lack of aeration when the bronchus of the exteriorized lobe is open to atmospheric pressure.

EXPERIMENTAL DEMONSTRATION

A mongrel dog was anesthetized and an endotracheal tube was inserted. Normal ventilation was maintained through the endotracheal tube by the use of a Bird respirator which permitted inspiratory and expiratory cycling at any desired pressure. A thoracotomy was performed and the left lower lobe was lifted through the incision, though its vascular and tracheobronchial continuity was maintained. The segmental bronchi to the lower lobe were identified and isolated. Simultaneous roentgenograms and photographs were taken at various stages of the experimental procedure, but with the different lobar positions required by roentgenologic and photographic needs.

In Figure 1, *A* and *B*, it can be seen that the lower lobe is fully deflated when the endotracheal tube is open to atmospheric pressure.

Figure 2, *A* and *B*, shows that inflation of the lobe is partially obtained by ventilation through a single patent segmental

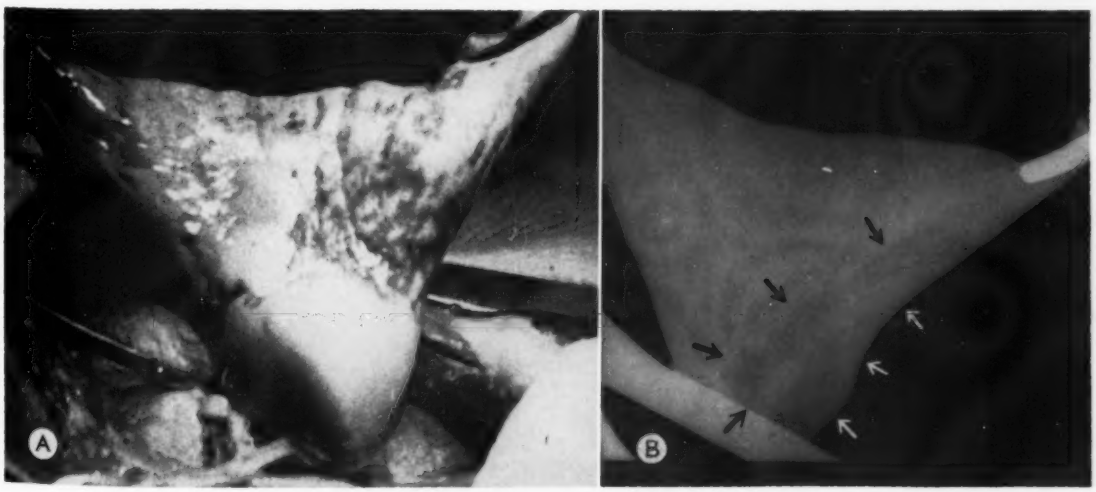

FIG. 2. Aeration of only a single segment is demonstrated. The photograph (*A*) and roentgenogram (*B*) were taken after ten minutes of cycled ventilation at 20 cm. of water pressure through a single patent segmental bronchus.

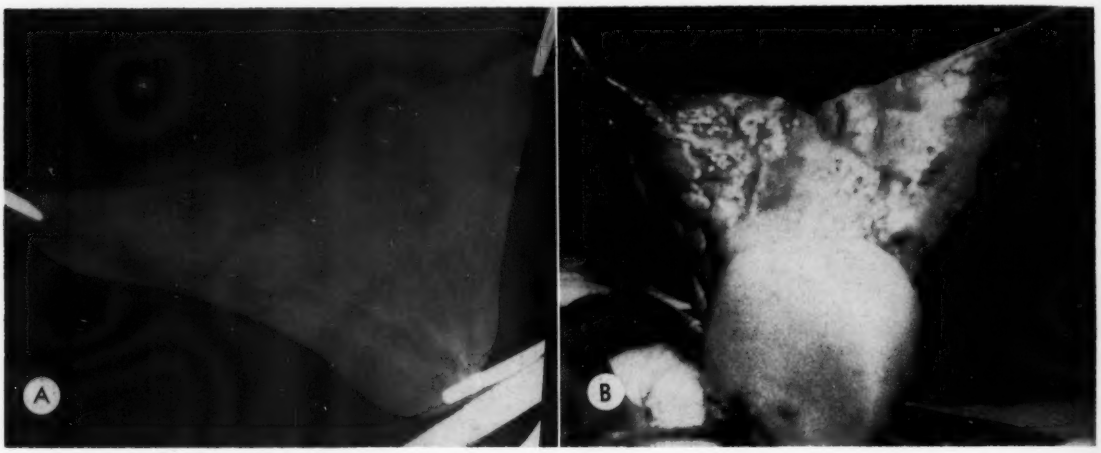

FIG. 3. Roentgenogram (*A*) and photograph (*B*) demonstrate total aeration of one segment and beginning inflation of the other segments. This degree of aeration followed within one minute of cycled ventilation at 40 cm. of water pressure through a single patent segmental bronchus.

bronchus under pressure of 20 cm. of water for a period of ten minutes. The other segmental bronchi of this lobe were clamped and totally occluded. The segment with the patent bronchus rapidly expanded and the segments with the occluded bronchi remained collapsed. Thus the pressure of 20 cm. of water (normal endobronchial pressure of the respiratory cycle varies from minus 2 cm. of water to plus 4 cm. of water during quiet respiration[1]) failed to inflate any segment other than that which had a patent segmental bronchus. There was continued collapse of the segments where the segmental bronchi remained clamped and obstructed.

Figure 3, *A* and *B*, shows inflation being obtained through a single patent segmental bronchus through which pressure of 40 cm. of water was exerted. The other segmental bronchi were occluded by clamping. This roentgenogram and photograph were taken one minute after pressure was applied by using the cycling Bird respirator. They show rapid expansion only of the nonobstructed segment of lung.

In Figure 4, *A* and *B*, taken after five minutes of cycled respiration at 40 cm. of

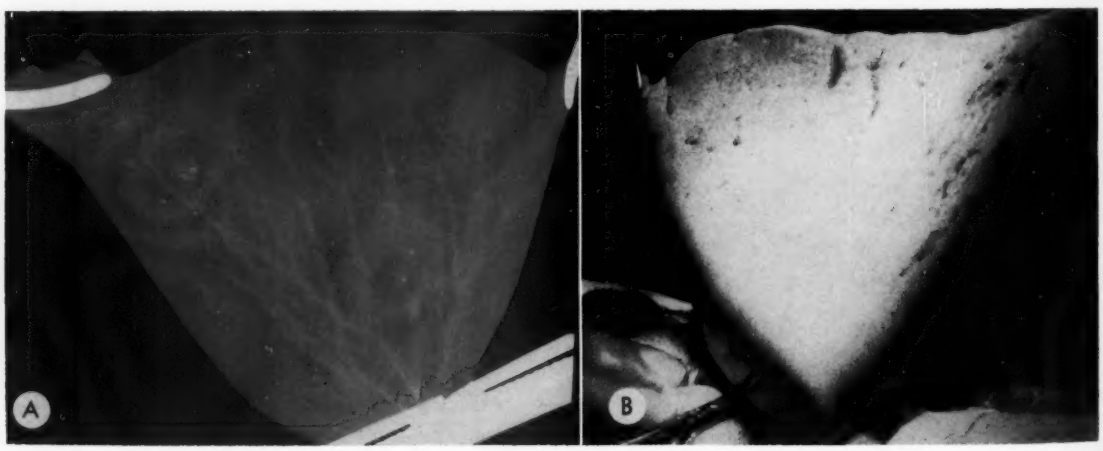

FIG. 4. Roentgenogram (*A*) and photograph (*B*) demonstrate complete aeration of the total lobe. This resulted from cycled respiration at 40 cm. of water pressure through a single patent segmental bronchus for a period of five minutes.

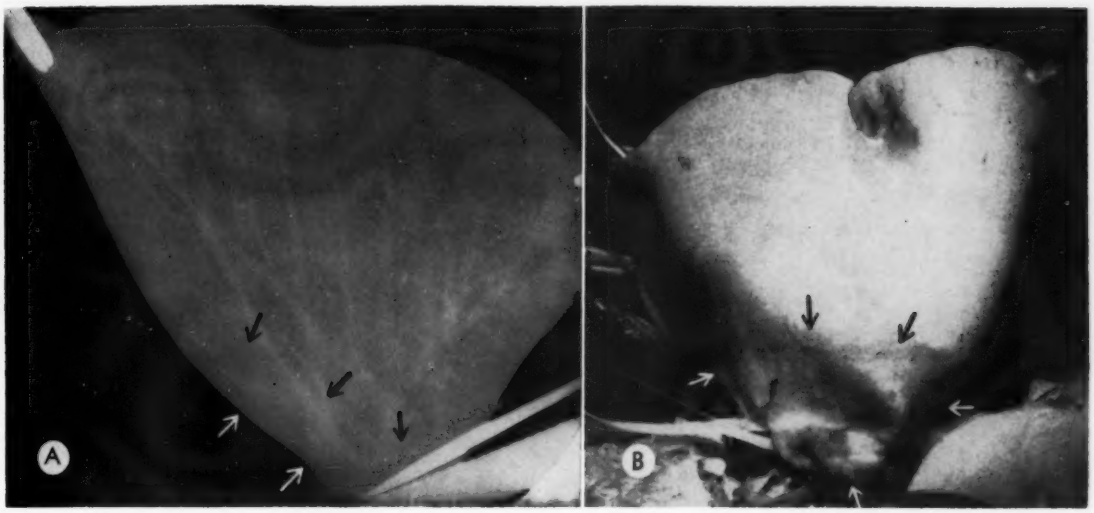

Fig. 5. (*A* and *B*) Following total inflation, deflation was permitted through a single patent segmental bronchus. Only that segment normally ventilated by the patent segmental bronchus collapsed significantly. Collapse of the other segments through the collateral channels was minimal after fifteen minutes.

water pressure, complete aeration of both the obstructed and nonobstructed segments of the lobe is demonstrated. The segments with obstructed segmental bronchi must have been inflated through the collateral channels across the intersegmental planes.

Figure 5, *A* and *B*, shows a totally inflated lobe which was permitted to deflate through a single patent segmental bronchus when the bronchus was exposed to atmospheric pressure. Only the nonobstructed segment collapsed. The segments with obstruction of their bronchi remained inflated. This indicated that, when inflated segments with obstructed bronchi are subject only to the inherent elastic recoil of the lung, the collateral pathways also become obstructed because of their check-valve mechanism. Marked compression must be exerted upon these segments to cause escape of the contained gases through their collateral channels.

REPORT OF CASES

Case 1 (Fig. 6, *A* and *B*). E.W., a forty-one year old Negro male, presented on a routine chest roentgenogram right upper lobe emphysema and a right parahilar mass of water density. The patient was asymptomatic. He was admitted to the hospital on October 22, 1958 for investigation and treatment.

Bronchoscopy was negative. The orifices of the three segmental bronchi of the right upper lobe were visualized and were normal. Bronchograms showed an obstruction of the bronchus of the anterior segment at a point just beyond its orifice. A large mass was seen adjacent to the obstructed bronchus. Laminagrams demonstrated the large parahilar mass as well as several smaller masses extending anteroinferiorly. The masses were seen to lie within the emphysematous lung tissue. Those segmental bronchi which filled with contrast material branched into normal appearing lung tissue.

On November 12, 1958 thoracotomy revealed that the anterior segment of the right upper lobe was markedly emphysematous and was compressing the apical and posterior segments. The right middle lobe and the right lower lobe showed no emphysematous changes. The parahilar mass contained clear viscid fluid. The lumen of the cystic mass was not in continuity with the tracheobronchial tree proximally or distally. There were several similar but smaller cysts more peripherally in the lung of the same segment. The bronchus of the anterior segment ended blindly at the proximal end of the cystic mass. The right upper lobe was excised. Microscopic sections showed bronchial cystic spaces lined by either columnar or pseudostratified columnar epithelium which rested upon laminated layers of fibrous tissue. There was no cartilage in the fibrous tissue. The surrounding pulmonary parenchyma was ex-

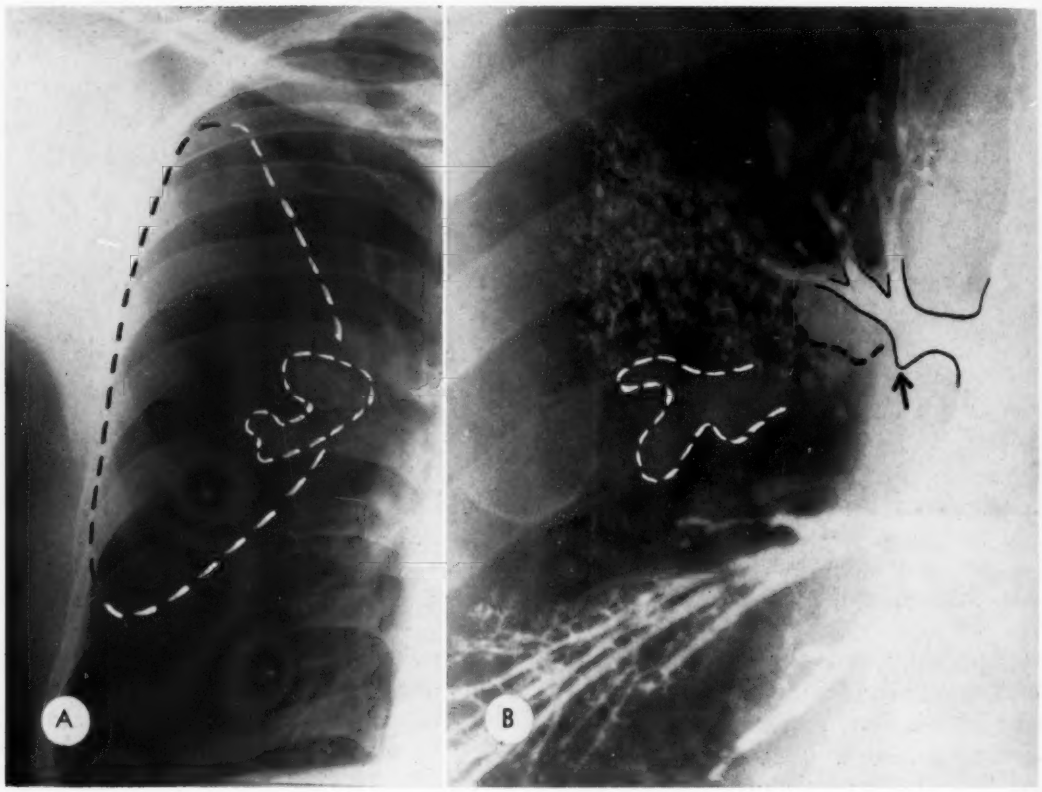

FIG. 6. Case I. (*A*) The mucocele is demonstrated lying within a localized area of emphysema. (*B*) The stump of the anterior segmental bronchus is shown. Adjacent to this lies the branched mucocele surrounded by emphysematous tissue.

tremely emphysematous and contained very few widely scattered pigment-containing macrophages. There were some adjacent regions where the pulmonary parenchyma was atelectatic; here the bronchi were normal in caliber and architecture.

In this patient the anterior segmental bronchus was totally occluded, secondary to anomalous deformities. Collateral ventilation maintained aeration of the segment, causing, ultimately, emphysematous changes.

Case II (Fig. 7, *A–D*). R.D.S., a twenty-five year old white male, presented on a routine chest roentgenogram a small right parahilar mass and peripheral to this an area of pulmonary emphysema. He was asymptomatic. The similarity of the roentgenographic appearance to that previously seen suggested the diagnosis of pulmonary cyst or mucocele in association with pulmonary emphysema.

The roentgenologic examination showed: (1) a 1.5 cm. parahilar mass with an air-fluid level within it on the routine upright roentgenogram. The lateral decubitus view showed a shift of the air-fluid level; (2) a cystic structure, irregular in outline, measuring up to 4 cm. in greatest diameter on posteroanterior and lateral laminagraphy. This appeared to lie within the superior segment of the right lower lobe; (3) the obstructive air-trapping phenomenon of pulmonary emphysema on expiration roentgenograms. The adjacent right lower lobe and right middle lobe were compressed and the mediastinum was shifted to the left. This was best seen on the bronchograms; and (4) apparent filling of all segmental bronchi, but with no flow of the contrast medium to the emphysematous parenchymal area on bronchograms.

The normal filling with contrast material of all segmental bronchi indicated that the bronchial cystic architectural alteration had occurred in a bronchial subdivision distal to a segmental bronchus. The apparently normal bronchogram, showing all segmental bronchi, is not a true indication of a completely normal bronchial tree, since alterations of architecture of the bronchi beyond the tertiary bronchi are difficult to discern.

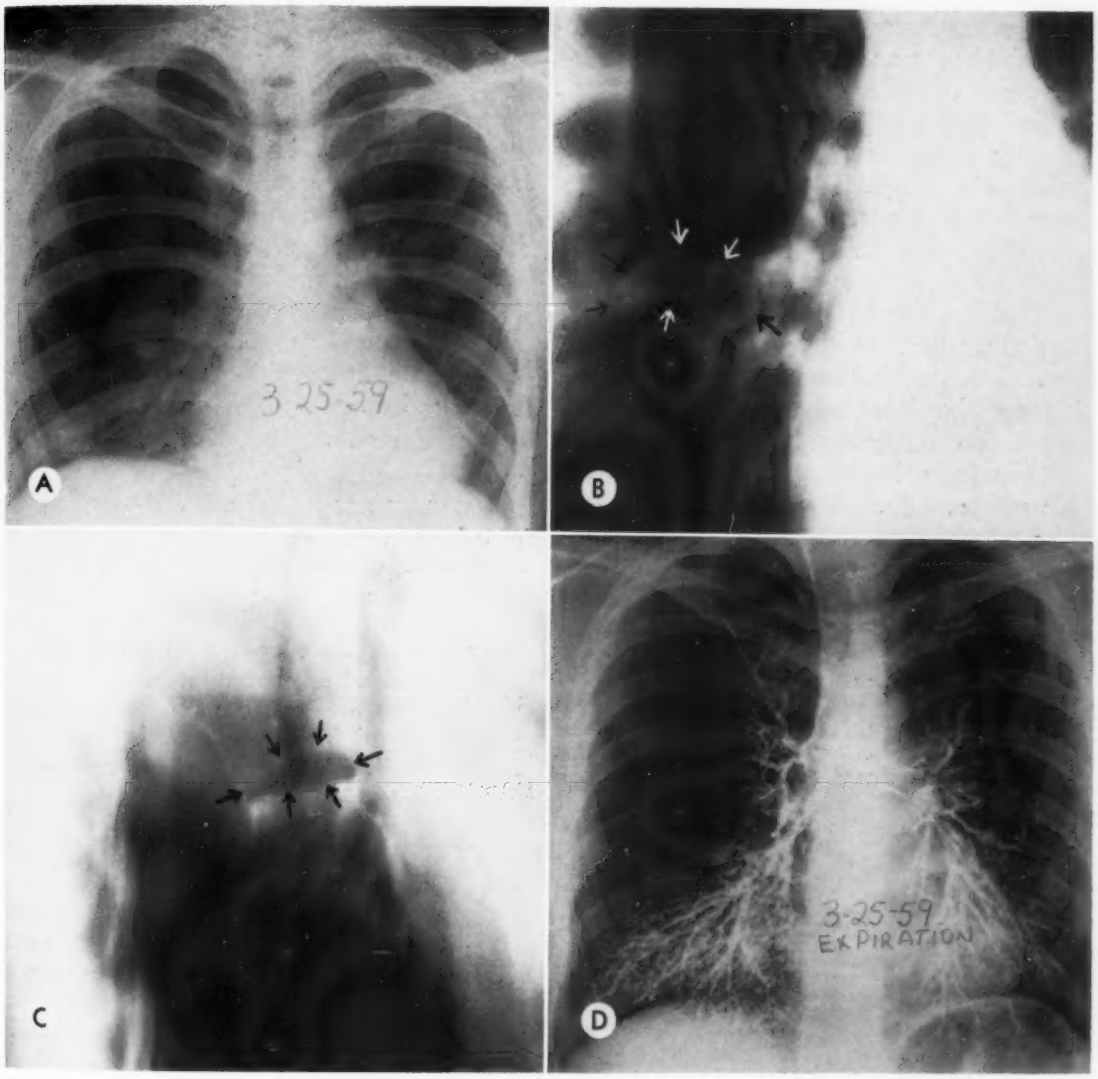

FIG. 7. Case 11. (A) The cystic structure showing a fluid meniscus is seen lying medial to an area of localized emphysema. (*B*) Posteroanterior and (*C*) lateral laminagrams further demonstrate the cystic structure lying within the area of emphysema. (*D*) Bronchogram made during expiration clearly shows the air-trapping phenomenon of the area of emphysema.

Again in this patient, an anomalous obstructive bronchial deformity resulted in collateral aeration followed by emphysematous changes of the lung parenchyma.

DISCUSSION

The experimental findings in the dog whose chest wall had been opened and whose lung was no longer subjected to the intrapleural pressures of the respiratory cycle cannot be applied wholly to the human lung lying within an intact thorax. However, pressure differentials between the obstructed and the nonobstructed segments in the lobe exposed to atmospheric pressure roughly parallel those of the segments within the intact thorax.

By applying a broad interpretation to these pressure measurements in the experimental animal in conjunction with our specific pathologic findings in clinical cases, we have evolved the following concept of the pathogenesis of emphysema in association with segmental bronchial occlusion. Segments with obstructed bronchi will remain collapsed with endobronchial pres-

sures of ordinary respiration. When endobronchial pressure is elevated to the range of 40 cm. of water pressure (as it so readily is in straining or coughing[1]), the obstructed segments become aerated through collateral channels from contiguous normal segments with patent bronchi. Once these segments are aerated, the subsequent escape of air from them is inhibited by the check-valve mechanism at the collateral channels. Over the years the segments aerated through collateral channels become increasingly distended and ultimately true obstructive emphysema occurs.

Aeration, rather than collapse of lung tissue beyond the point of segmental bronchial obstruction, depends on continued collateral ventilation. However, collateral channel air drift may be impeded by the following factors:[1] (1) insufficient pressure differential between the segments with patent bronchi and those with obstructed bronchi; (2) accumulation of bronchial secretions distal to the point of bronchial obstruction and retrograde filling of the alveoli with these secretions; and (3) inflammatory exudate and inflammatory tissue organization in the lung tissue. Under these conditions, continued aeration is not possible, since the "wet lung" or the "organized lung" will obviously not permit continued collateral respiration. Consequently, collapse of the lung tissue often follows segmental bronchial obstruction.

SUMMARY

An experimental demonstration of collateral respiration and aeration of lung segments in which the bronchi were obstructed is presented. Clinical cases showing emphysema of such segments caused by the abnormal mechanics of chronic collateral respiration are reported.

When localized areas of emphysema or hyperaeration are found, the basic etiologic factor of segmental or subsegmental bronchial obstruction or obliteration should be sought. Then the role of collateral respiration in the pathogenesis of regional emphysema or hyperaeration will be recognized and understood.

Morris M. Culiner, M.D.
Mount Zion Hospital and Medical Center
1600 Divisadero Street
San Francisco, California

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IDIOPATHIC UNILATERAL HYPERLUCENT LUNG*

REPORT OF A CASE COMPLICATED BY PNEUMONIA

By HERBERT BILLINGSLEY FRANCIS, CAPTAIN, USAF(MC)
Wheelus Air Force Base
TAGURIA, LIBYA, NORTH AFRICA

ONCE described and recorded in the literature, newly recognized syndromes are usually immediately discovered in increasing numbers.[2] So it will probably be with idiopathic unilateral hyperlucent lung which has also been termed the "lazy lung."[1]

It is intended here to report one additional case which, I believe, demonstrates to good advantage the classic roentgenologic signs described by Margolin *et al.*[3]

REPORT OF A CASE

N.B., a twenty-nine year old white female, was referred for a routine chest roentgenogram in February, 1959. This revealed abnormal radiolucency of the entire left lung due to a marked decrease in the vascular pattern on this side (Fig. 1). There was no evidence of overexpansion on the left and it was the initial impression that this represented absence or hypoplasia of the left pulmonary artery. The patient was subsequently hospitalized for further diagnostic studies.

Past history revealed a "double pneumonia" at the age of two years of such severity that her physician did not expect her to recover. Until about the age of ten years, the patient had a persistent "wet cough" with an apparent predisposition to numerous respiratory infections. Since that time, however, she has been asymptomatic and in excellent health. There has been no dyspnea associated with ordinary exertion or hemoptysis at any time. The chest roentgenograms of her two living children were normal. The family history was noncontributory.

Physical examination disclosed a quite healthy appearing young white female. All vital signs were normal. There was no difference observed in the expansion of the two sides of the thoracic cage. The only positive physical finding was the presence of loud, medium dry rales occurring at the terminal portion of inspiration over the entire left hemithorax, which persisted following coughing. On direct questioning, the patient recalled several physicians in the past commenting on the auscultatory finding of adventitious sounds in her left chest. Routine laboratory work was within normal limits.

Fluoroscopy during respiration revealed some restriction of the left hemidiaphragm with no significant mediastinal shift. The left hilus was quite small and normal pulsations of the hilar vessels were not observed. The most striking finding was a constant density of the entire left lung field with failure to "cloud up" normally on expiration (Fig. 2).

Pulmonary angiography was performed by injecting 30 cc. of 90 per cent hypaque with a No. 13 needle into an antecubital vein. The

FIG. 1. Routine chest roentgenogram taken during inspiration reveals increased radiolucency of the entire left lung, apparently due to a decrease of vascular shadows, with no evidence of overexpansion.

* This paper represents the personal viewpoint of the author and is not to be construed as a statement of official Air Force policy.

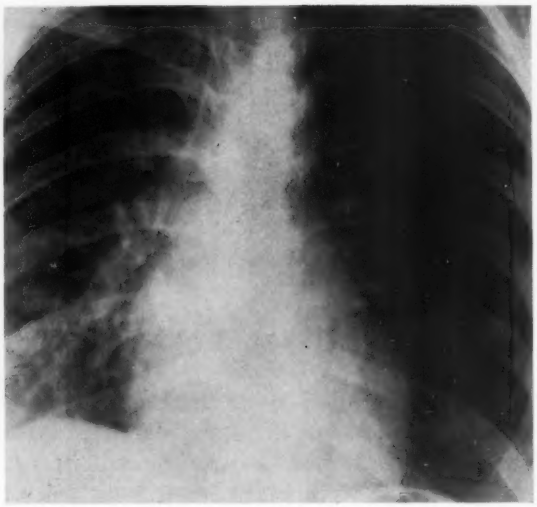

FIG. 2. Expiration roentgenogram shows normal clouding of the right lung field without increase in density on the left side. There is no significant mediastinal shift.

angiogram demonstrated a marked diminution of the pulmonary circulation on the left side (Fig. 3). Bronchography revealed a normal anatomic pattern of the major and minor bronchi bilaterally, but on the left side an unusual type of terminal bronchiectasis or clubbing was demonstrated with no alveolar filling even on a delayed roentgenogram (Fig. 4 and 5).

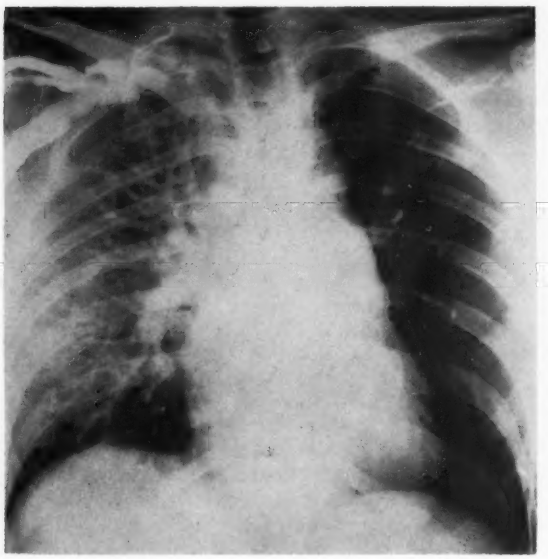

FIG. 3. Pulmonary angiogram proves the presence of a hypoplastic left pulmonary artery with normal or increased circulation to the right lung.

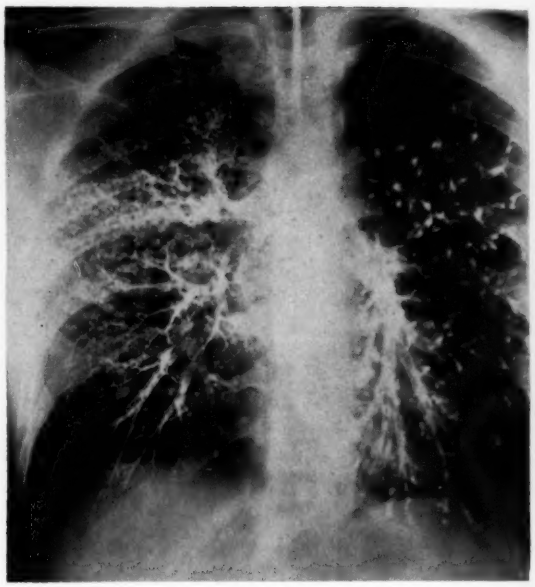

FIG. 4. Bronchogram demonstrates the terminal "club type" of bronchiectasis on the left side with normal patency and arrangement of the major bronchi. Note absence of alveolar filling. The right side is normal.

Approximately four months following the above procedures, the patient was admitted to the hospital with clinical symptoms and signs

FIG. 5. Oblique bronchogram of the left upper lobe area shows the terminal clubbing in detail.

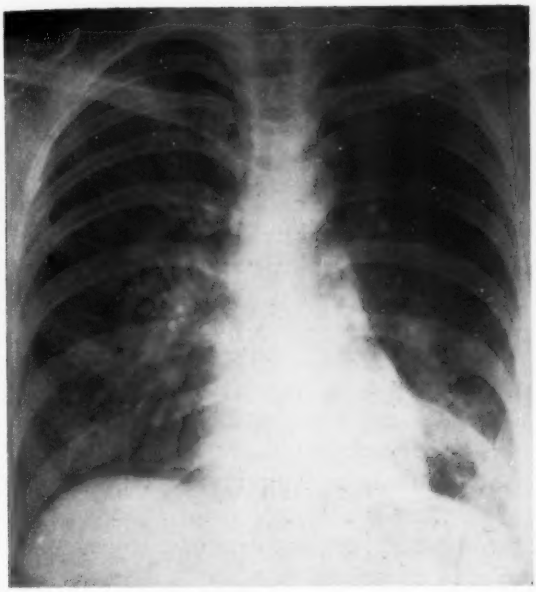

FIG. 6. Posteroanterior roentgenogram shows acute left lower lobe pneumonia, which developed four months following the above procedures and cleared rapidly on antibiotic therapy leaving no residual.

of an acute left lower lobe pneumonia. Roentgenography at that time revealed a typical pneumonic infiltration in the left lower lobe (Fig. 6) which cleared rapidly on antibiotic therapy, leaving no change in the appearance of the follow-up chest roentgenogram from the original (Fig. 1). This was the first recorded pulmonary infection since childhood.

DISCUSSION

The aforementioned changes, consisting of (1) increased radiolucency of an entire lung or lobe, with a constant normal volume during inspiration and expiration; (2) a small hilar shadow with diminution in pulmonary vascularity proved by pulmonary angiography, and (3) the peculiar terminal bronchiectatic pattern with lack of alveolar filling but with normal patency and distribution of the major and minor bronchi, characterize the roentgenologic syndrome of idiopathic unilateral hyperlucent lung.

Many of the patients previously reported with this syndrome[2] have had varying degrees of respiratory difficulty. The present case history is not one of recurrent pulmonary infections or of pulmonary symptomatology and, in fact, only one severe respiratory illness had occurred at the time of her original workup.

The etiology is not definitely known, but if the vascular abnormality is congenital, the possibility that the bronchiectasis may be acquired is suggested in the present case by the rather severe bout of pneumonia in childhood which may have resulted in permanent changes on the hypovascularized side.

SUMMARY

An additional case demonstrating classic roentgenographic, fluoroscopic, and bronchopulmonary changes of the idiopathic unilateral hyperlucent lung syndrome and complicated by an acute pneumonia on the abnormal side is reported.

Box 23, 7272 USAF Hospital
APO 231, New York, New York

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ROENTGENOLOGIC ASPECTS OF ASBESTOSIS*

By M. HURWITZ, M.D., D.M.R.D.
JOHANNESBURG, SOUTH AFRICA

THE roentgenologic features of asbestosis have been described from time to time during the past few decades. However, the literature on the subject is still rather scanty and often misleading. Here in South Africa, where the production of a considerable proportion of the world's asbestos has been going on since approximately 1893, we have had the opportunity, particularly in more recent years, of examining large groups of workers from specific areas, notably from the Kuruman and Lydenburg districts. A study of the evolution of roentgen manifestations in individual cases, as in silicosis, has not yet been possible. Regular initial and periodic examinations have been instituted only lately. Careful correlation with necropsy findings, in contrast to the work which has been done on gold miners' silicosis, has been confined to relatively few cases. Likewise, correlation with the results of clinical and physiologic investigation has been limited.

EARLY ASBESTOSIS

It has been suggested repeatedly that a negative period exists when the disease may be present to a significant degree clinically, without being manifest roentgenologically. Judging by the very limited biopsy and pathologic material available to date, there certainly appears to be some evidence in support of this contention. This obviously has a bearing on the important and very difficult problem of the diagnosis of asbestosis in its early stage. The limits of the normal and abnormal are far more difficult to define in early asbestosis than in early silicosis, even when there is an adequate history of exposure.

Factors such as an indifferent roentgenographic technique, obesity, poor film quality, or exposure of the film during insufficient inspiration all contribute to misleading results. Roentgenography in multiple projections of the chest and specialized techniques, including macroroentgenography, are not likely to be of much help. At present, a pre-employment examination followed by a series of periodic examinations, utilizing a standardized and comparable roentgenographic technique, has the most to offer in solving the problem of making an early roentgenologic diagnosis of asbestosis and, incidentally, of also assessing the rate of progression.

As a result of observations in many individuals who have long records of service in asbestos mines and mills, it has been possible to draw up a rough classification of the more definitive roentgenographic changes that are found. These may be divided broadly into pleural changes and parenchymal lung changes. Frequently a combination of both occurs. The complications of asbestosis also need to be considered.

PLEURAL CHANGES

These by far outnumber the so-called diffuse lower zone fibrotic lung changes emphasized by previous workers. The pleural changes may be nonspecific in the form of uni- or bilateral, parietal or interlobar, thickenings of varying extent. Obliteration of the costophrenic sulci as well as diaphragmatic and pleuropericardial adhesions also occur, statistically, more frequently among asbestos workers than in other groups.

A localized recent basal pleuritis may be observed but not frank or copious pleural effusion. The veiling and lack of radiolucency in lung areas where pleural pathology exists evidently appears, in many cases,

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The views expressed in this paper are those of the author and are not to be construed as reflecting the policy of the Pneumoconiosis Bureau or of the Department of Mines of the Government of the Union of South Africa.

to be due mainly to pleural fibrosis, rather than to underlying pulmonary fibrosis. As a result of extensive pleural thickening, the cardiac outline and also the outline of the diaphragm are unsharply defined. When pleuritic adhesions are present, distortion and irregularity of contour in the form of "peaking" and "tenting" are noted. On fluoroscopy, restricted diaphragmatic mobility and diminished chest movement may be seen. It is well to remember, however, that in spite of the frequency with which pleural thickening *per se* is found in asbestos workers, this is also a fairly common isolated finding in the course of ordinary roentgenologic studies. Therefore, it would be highly presumptive to accept such evidence alone as being diagnostic of asbestosis, even in cases where a satisfactory occupational history is present.

However, a more specific pleural pathology has recently come to light in the form of added calcification and the deposition of typical pneumoconiotic plaques (Fig. 1, *A* and *B*). This has been noted as a regularly recurring feature in old asbestos workers with varying periods of service. Calcific plaque formation may be minimal or extensive, linear or occurring in irregular patches; it is usually bilateral and more or less symmetric. The plaques are often distributed along the parietal pleura, particularly in the middle and lower zones, but it is worth noting that extensive areas of calcification may be found along the anterior aspect and also that both the diaphragmatic and mediastinal pleura are commonly involved. The asbestotic plaques are different in appearance and in character from silicotic plaques, which, though not common, are usually seen in the upper zones, peripherally. It may also be empha-

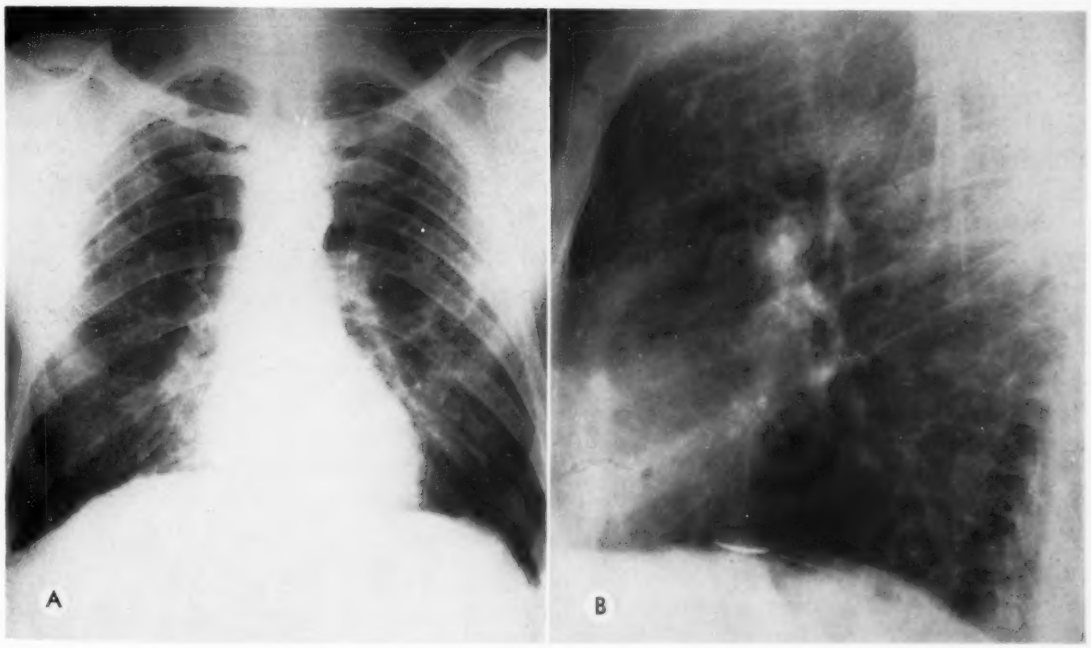

Fig. 1. (*A*) Extensive pleural plaque formation over both lung fields. Right paramediastinal and bilateral diaphragmatic plaques are also seen. (*B*) Lateral roentgenogram shows the plaques disposed along the anterior aspect of the chest and adjacent to the diaphragmatic surface.

White miner, aged fifty, with fifteen years' service as an asbestos miner in the Kuruman district, Northern Cape Province. Complained of slight dyspnea on exertion of several years' duration and pain over the right base. A cholecystectomy was performed in 1947, but no other previous major illness was present. Examination showed a well built individual, height 6′2″, weight 198 pounds. The chest expansion was two and one half inches. There was no finger clubbing. Harsh breath sounds were heard. The heart was normal; blood pressure was 120/80; the electrocardiogram was normal. A Masters Effort Tolerance Test showed definite mild disability.

sized that in pure asbestosis, in contradistinction to silicosis, associated "egg shell" lymph node calcification is singularly absent. Evidently the lymphatic drainage apparatus of the lung is not implicated to the same extent in asbestosis as it is in the silicotic process following the retention of dust in the lungs.

When massive plaque formation is present, a rather characteristic bizarre pattern is produced. This is obviously different in appearance from extensive pleural calcification due to other causes, such as tuberculosis, chronic empyema and old trauma. According to recent publications, this particular pattern appears to be common to, and is diagnostic of, a group of pneumoconioses resulting from exposure to certain silicate dusts.

Smith[5] in 1952 reported a high incidence of similar calcium deposition in the pleura in a number of occupational groups exposed to various dusts, such as tremolite talc (6.3 per cent of cases); calcimine (1.7 per cent); mica (1.6 per cent); dust produced in the manufacture of bakelite insulators (1.5 per cent); and asbestos (no case). Calcium depositions were found in 35 of 8,779 subjects examined. It is noteworthy that Smith was unable to demonstrate pleural calcifications resulting from asbestos dust in the group of 261 asbestos workers. Gloyne[2] in 1938, in his classic description of the pathology of asbestosis, did mention the occurrence of "stiff, hornlike plaques." However, the first reference in the literature to asbestotic plaques demonstrated roentgenographically was made only as recently as 1955, in 1 case reported by Jacob and Bohlig. In 1956, Frost, Georg and Møller[1] of Denmark reported 11 such cases from a group of 31 insulation workers exposed for many years to mixed dust containing asbestos.

Our own experience has been that, since the registration of asbestos mines in 1953 under the 1946 Mines Act, we have seen numerous such cases, more expecially as the result of the very large surveys which have been conducted from January, 1954 to date. After constant work with silicotic beneficiaries among gold miners, the sudden presentation of significant numbers of old asbestos workers showing this new pattern of calcific plaque formation has been most striking (Fig. 2). Since then we have continued to be impressed by the fact that we seldom fail to find several such cases in every large group of roentgenograms submitted from the asbestos areas. Conversely, not a single case showing these typical plaques was ever found among all the roentgenograms of gold miners, and of the large groups mining coal, copper, iron, chrome and manganese.

LUNG CHANGES

These may be of four types:

1. As pointed out, diffuse interstitial fibrosis occurs commonly in combination with the pleural changes which have already been described (Fig. 3). The diffuse type of fibrosis found in asbestosis should

FIG. 2. Sclerotic pleurisy with extensive mediastinal, paracardiac and diaphragmatic pleural plaques.

Colored worker, aged fifty-one, with a twenty-nine year (1925–1954) history of underground asbestos mining in Northern Cape Province. He had also worked in diamond diggings in Northern Cape Province for four years (1921–1925). Examination revealed a tall, poorly nourished, weak individual, height 5′11″, weight 135 pounds, with flattened chest which had an expansion of one inch. The breath sounds were harsh and there were some marginal crepitations. The heart showed no appreciable disease; the blood pressure was 140/80. The individual was considered to be fit for light work only.

be differentiated etiologically from pulmonary collagenosis such as occurs in rare cases of silicosis, in scleroderma, rheumatoid arthritis, bilharziasis, in the general group known as "honeycomb lung," and in the so-called Hamman-Rich syndrome. Pleural thickening, which is so frequently seen in asbestosis, is not a constant accompanying feature in any of these other collagen diseases.

2. Less frequently, there are lung changes alone, presenting the classic pattern of simple uncomplicated diffuse pulmonary fibrosis (Fig. 4). This may vary in degree. There may be merely a homogeneous clouding and haze over the lung fields, particularly over the lower zones, producing a ground glass appearance. When very mild this can present great difficulty in diagnosis, especially when technical quality is questionable and when no previous roentgenograms are available for comparison. A more definite stage is one which shows a fine striated, fibrillar change in the lung structure, causing progressive reduction of pulmonary radiolucency with blurring and masking of the vascular lung markings (Fig. 5). Eventually, an advanced stage of diffuse lung induration is reached with very marked pulmonary hypoventilation which gives an unmistakable picture (Fig. 6).

Fig. 4. Parenchymal pulmonary asbestosis with diffuse pulmonary fibrosis, which is more marked in the lower lung areas.

European, aged sixty, worked for many years in an asbestos mine in the Lydenburg district, Transvaal, both underground and on the surface in the mill. Clinically diagnosed as bronchitis with emphysema (and early cor pulmonale?).

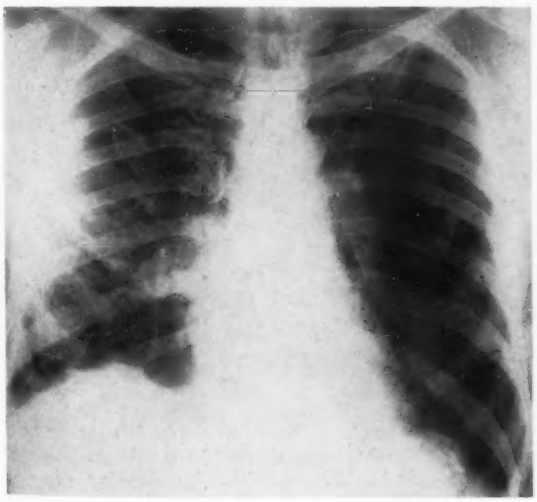

Fig. 3. Slight bilateral pulmonary fibrotic changes with dense compact pneumonic area of fibrosis in left upper lobe. The pleural thickening is particularly well marked on the right side and bilateral calcific pleural plaques are demonstrated.

Colored asbestos miner, aged forty-four, with a record of twenty-eight years' service (from 1926 on) in Cape Blue Mines. Clinically he had no complaints and apparently was a healthy individual of medium build, height 5′7″, weight 143 pounds. The chest expansion was one and one half inches. Reduced resonance and distant breath sounds were noted on the right side, especially at the right lung base, with occasional crepitations. The heart was clinically normal; the blood pressure was 130/90. He was assessed fit for ordinary work.

3. Some cases present with localized areas of homogeneous, compact, pneumonic consolidation and fibrosis. These areas may occur in any part of the lung. They do not appear to be disposed in a regular lobar or segmental pattern as in the pneumonias; nor are there any accompanying infiltrative changes such as one sees in pulmonary tuberculosis. The pneumonic areas may be multiple and occasionally only one lung is involved. Associated pleural thickening is usually seen. The precise nature of these pneumonic changes is not evident and still requires further investigation. Moreover, these lung changes do not in any way re-

FIG. 5. Pulmonary asbestosis with diffuse lung fibrosis, particularly well marked in the middle and lower zones. The right cardiac border and the right dome of the diaphragm are unsharply defined.

Colored miner, with a history of twenty-six years of asbestos mining in Cape Blue Mines. He worked underground from 1906 on, is now a debilitated pensioner aged seventy-seven, and complains of bouts of coughing and dyspnea. Examination showed a flat chest with poor air entry and expansion of one half inch, with crepitations at the lung bases.

semble the progressive massive fibrosis which occurs in complicated silicosis and in coal workers' pneumoconiosis.

4. Due presumably to associated silica exposure, a well-marked nodular lung pattern is occasionally encountered in asbestos workers (Fig. 7). The picture may be indistinguishable from silicosis. On the other hand, a number of cases show stigmata of both asbestosis and silicosis in the form of generalized fibrosis accompanied by nodule formation. It is significant that among this group there were also several cases which exhibited fairly extensive lymph node calcification such as one sees among old silicotics. Thus far, we have observed these features which are indicative of silicosis only among workers from the Cape Blue area, where a high percentage of silica and iron has been reported in the mined asbestos.

COMPLICATIONS

The frequency of the various intrathoracic complications, which are encountered in some of the pneumoconioses, has not yet been accurately assessed in asbestosis. Pulmonary tuberculous lesions evidently occur as frequently among asbestos workers of all races as in the gold miners. A variety of forms of pulmonary tuberculosis has been observed, including extensive and frankly active lesions with cavity formation and even with disseminated miliary infiltration. While lung cancer has so far been extremely rare in our series, pleural malignancy in the form of mesothelioma has been

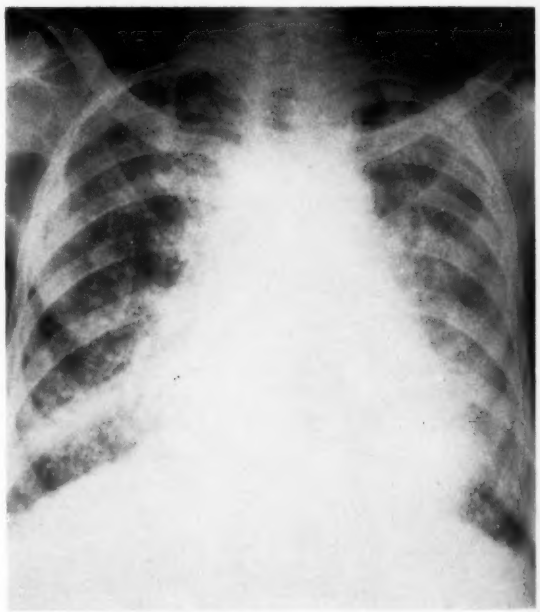

FIG. 6. Advanced asbestosis with intense fibrosis throughout both lung fields. An element of nodular fibrosis is also evident, presumably due to associated silica exposure. The heart shadow is enlarged.

Colored miner, aged fifty-four, worked from 1916 to 1954 in Cape Blue Mines, Prieska district. Of these thirty-eight years of mining, twenty-seven years were spent underground. (He holds a blasting certificate issued in 1920 and valid for asbestos mining in Cape Province only.) Symptoms of cough and shortness of breath were present for the past ten years. Examination showed poor physique, height 5'6 1/2", weight 135 pounds, obviously dyspneic with crepitations all over the chest but mostly at the bases. Repeated sputum tests were negative for tuberculosis. He was considered fit for very light work only.

Fig. 7. Widespread nodulation in the lung fields, indistinguishable from classic silicosis. Note small bilateral diaphragmatic pleural plaques.

This patient had a history of many years' service as an asbestos miner in the Griqualand West district, Cape Province.

Fig. 8. Pleural mesothelioma, with induced right-sided pneumothorax. Diffuse pleural thickening and numerous rounded, nodular tumor masses on the parietal pleura and also on the visceral pleura overlying the collapsed right lung are demonstrated. Only secondary pulmonary hyperemia is evident in the left lung with no frank signs of pulmonary asbestosis.

This patient had a previous history of exposure to asbestos dust in the Kuruman district, Northern Cape Province.

relatively frequent in individuals exposed to asbestos dust (Fig. 8).

SUMMARY

1. The roentgenologic features of asbestosis as seen among asbestos workers in South Africa are described and discussed.

2. Emphasis is placed on the pleural changes, which are found more frequently than the classic diffuse pulmonary fibrosis. Pleural involvement also occurs frequently in association with lung fibrosis.

3. A characteristic pattern of sclerotic pleurisy presenting in the form of calcific pleural plaques is described. Although this pattern may be seen in a number of pneumoconioses resulting from exposure to certain silicate dusts, its incidence in asbestosis has hitherto received scant attention in previous publications.

4. The complications of asbestosis are briefly referred to, including pleural mesothelioma, which appears to be relatively common among asbestos workers in the northern Cape Province of South Africa.

P.O. Box 1756
Johannesburg
South Africa

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DIATOMITE PNEUMOCONIOSIS: ROENTGEN CHARACTERISTICS AND CLASSIFICATION

By WALDO R. OECHSLI, M.D.,* GEORGE JACOBSON, M.D.,†
and ARMAND E. BRODEUR, M.D.‡
LOS ANGELES, CALIFORNIA

THE purpose of this report is to describe certain roentgenographic aspects of pneumoconiosis seen in diatomite workers and to propose a roentgenographic classification of these changes. It is based on a review of the chest roentgenograms of 869 workers in five plants who participated in the survey conducted by the United States Public Health Service in 1953 in cooperation with the California, Nevada and Oregon State Departments of Health. A comprehensive and detailed report of this study is found in United States Public Health Service Publication 601, 1958[4] entitled "Pneumoconiosis in Diatomite Mining and Processing."

Detailed environmental studies were made to determine the extent and nature of the dust exposure. The medical studies of the employees in the five participating plants included occupational and medical histories, physical examination, roentgenograms of the chest, electrocardiograms, hematologic and urinary examinations, intradermal skin tests with tuberculin, histoplasmin and coccidioidin and pulmonary function tests. When indicated, bacteriologic studies for tuberculosis were performed. The follow-up studies included biennial chest roentgenograms on the workers in the plants and those with over two years of employment who had left the industry.

Diatomite pneumoconiosis is a relatively uncommon pulmonary condition resulting from protracted inhalation of certain forms of diatomaceous earth. Although diatomaceous earth has been known and used for approximately 2,000 years, its disease-producing propensities were first reported in the medical literature by Legge and Rosencrantz[6] in 1932. However, it was not until 1946 that it was acknowledged that exposure to certain forms of diatomaceous earth dust could result in a disabling and sometimes fatal disease.[1]

Diatomaceous earth—a light, porous substances of white, yellowish or gray color—is the fossilized skeletal remains of microscopic, aquatic, single-cell plants (algae). It is synonymous with diatomite, Kieselguhr, tripolite, infusorial earth, fossil flour and fossil silicon. In its crude state diatomite contains about 85 per cent amorphous silicon dioxide by weight.

The industrial mining of this substance dates back to 1860 in Europe (Hanover, Germany, and North Ireland) and it has been mined for approximately sixty years on the North American continent. California, Nevada, Oregon and Washington contain nearly all the commercially exploited deposits in the United States. There are about 1,000 employees engaged in diatomite mining and milling industries in these western states of whom about 800 are in California.

The diatomite-producing industry in the United States is a relatively small one. Five plants employing approximately 1,000 persons produce practically all of the diatomite in this country. However, the production of diatomite by no means represents the only method of exposure to this material. It is shipped in great quantities to all parts of the world and is used in a very wide variety of technologic processes. It plays an important part in the sugar industry, in the filtration of unfermented fruit juices, syrups, wine, beer, dry cleaning

* Bureau of Tuberculosis Control, California State Department of Public Health.
† Departments of Radiology, Los Angeles County Hospital and University of Southern California School of Medicine.
‡ Division Special Health Services, United States Public Health Service. (Present address, 141 Horseshoe Drive, Kirkwood, Missouri.)

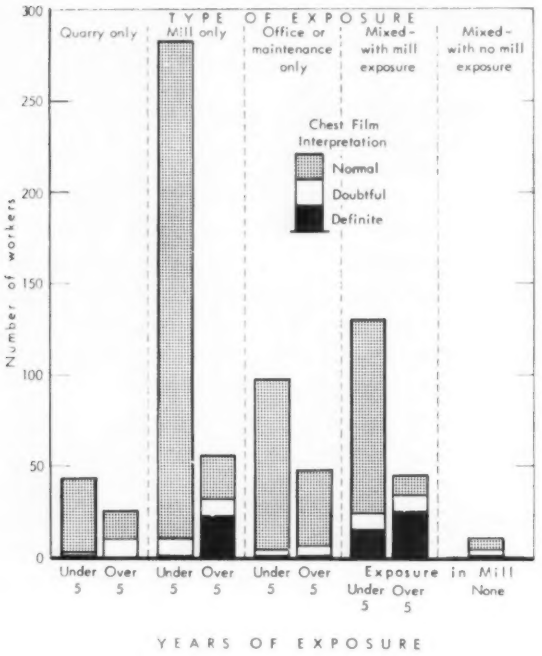

FIG. 1. Interpretations of chest roentgenograms according to type and duration of exposure.

solvents, water for drinking purposes, swimming pools, etc. It is used as a filler in paints, varnishes and lacquers in addition to the manufacture of special types of paper. It aids in the manufacture of insecticides, metal, glass and automobile polishes, detergents, plastics, concrete, matches and many other products. Its low heat-conducting properties lead to widespread use in insulation for boilers, stills, furnaces, kilns, and petroleum-cracking furnaces. In the chemical field it finds use as a catalyst.

Multiple processing techniques, including drying diatomite at temperatures ranging from 300°F. to 800°F., convert the crude diatomaceous earth to the "natural" powder. In addition to "natural" diatomite, two other forms are manufactured—calcined and flux-calcined. Straight calcining is done in a rotary kiln at temperatures ranging from 1,600 to 2,000°F. In low-temperature calcining little, if any, of the amorphous silica is converted to cristobalite, a crystalline form of silica; but as much as 20 to 30 per cent may be converted in high-temperature calcining. Flux-calcining consists of mixing the purified "crude" with a flux, usually sodium carbonate, and passing this mixture through a rotary kiln at 2,000° F. Approximately 40 to 60 per cent of the amorphous silica may be converted to cristobalite during this process along with the production of about 1 per cent tridymite, another form of crystalline silica.

The environmental studies of the survey showed that the median size of the airborne dust particles varied from 1.0 μ for straight calcined diatomite, 1.1 μ for flux-calcined material up to 2.5 μ for the crude diatomite. Median atmospheric dust concentrations in major operating areas ranged from 1 to 66 million particles per cubic foot of air (MPPCF), as determined by standard light field techniques. Five MPPCF of the cristobalite-containing product and 20 MPPCF of the crude or natural product have been suggested as the maximal concentration to which workers should be exposed.[4] Table 1 shows the percentage of cristobalite in the various diatomite materials.

Pathologic studies of diatomite pneumoconiosis have been reported by Nordmann[7] in 1943, Vorwald and co-workers[11] in 1949, Carnes[3] in 1954 and Caldwell[2] in 1958. These investigators concluded that protracted inhalation of diatomaceous earth produces chronic pulmonary disease in man. They are in agreement that the histopathologic changes in lung and lymph node differ in many respects from those produced by quartz.

TABLE I

WEIGHT PERCENTAGE OF CRISTOBALITE IN PARENT MATERIAL, SETTLED DUST, AND AIRBORNE DUST, ACCORDING TO PRODUCT

(5 Plants Combined)

Product	Parent Material	Settled Dust	Airborne Dust
Natural	0–1	Less than 1	Less than 5
Straight-calcined	15–21	27–52	17–22
Flux-calcined	49–61	38–75	32
All types (mixed)	—	25	16

The pathologic findings in 27 workers studied by Carnes[3] indicated that these cases fell into two groups corresponding to the simple and confluent forms. In simple pneumoconiosis the histopathologic changes consisted of "accumulation of dust cells in the alveoli, in the interstitial tissue of the lung, including the alveolar walls, and in the hilar lymph nodes with either no fibrosis or in the long-standing cases a very delicate reticular fibrosis." Conspicuous by their absence were "the cardinal features of typical silicosis; namely, the focal, discrete hyalin nodules and the whorled pattern of collagenous fibers."

In those individuals with the confluent form, there was "in addition to the foregoing changes more or less massive confluence of the lesion in the upper one-third of the lungs, with necrosis and marked fibrosis." In at least 4 of the 6 cases of the latter type, the patient's demise was attributed to the pneumoconiosis. Carnes drew no conclusions as to the role, if any, of infection in the production of these coalescent lesions. Varying degrees of focal emphysema were associated with the diatomite lesion, the lesion proper having a stellate appearance and the "focal emphysema associated with the focal dust reaction recalls the lesions in the lungs of the Welsh coal miners reported by Gough and others. However, none of these cases have shown the advanced degree of focal emphysema described in the coal miners."

Fig. 2. LN_2. Fine nodular and linear deposits in both lungs above the level of the third rib anteriorly. Changes such as this may easily be mistaken for tuberculosis.

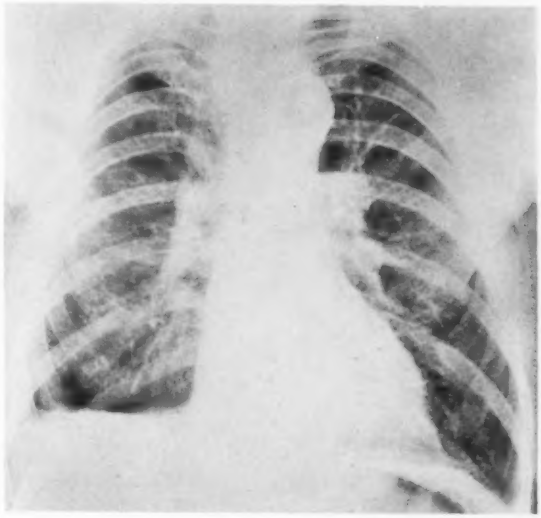

Fig. 3. LN_3. Profuse granular densities rather evenly distributed throughout both lungs.

Caldwell[2] concluded that diatomite pneumoconiosis in tuberculin negative individuals follows a different pathologic and roentgenographic pattern from that in tuberculin positive individuals. However, it should be noted that the number of cases reviewed in each group was small and of doubtful statistical significance.

ROENTGENOGRAPHIC STUDY

Stereoscopic 14×17 inch chest roentgenograms of 869 employees (94 per cent of the total number of employees in the five plants) were obtained. Roentgenograms of unacceptable quality were eliminated. The chest roentgenograms were inspected initially by the physician members of the field team for quality control and for detection of abnormalities requiring the immediate notification of the employee's private physician.

Prior to the interpretation of these roentgenograms, the authors reviewed a number of proved cases of diatomite pneumoconiosis and compared the pathologic and roentgenologic changes. It was agreed that the roentgenologic changes fell into two major categories. One consisted of fine

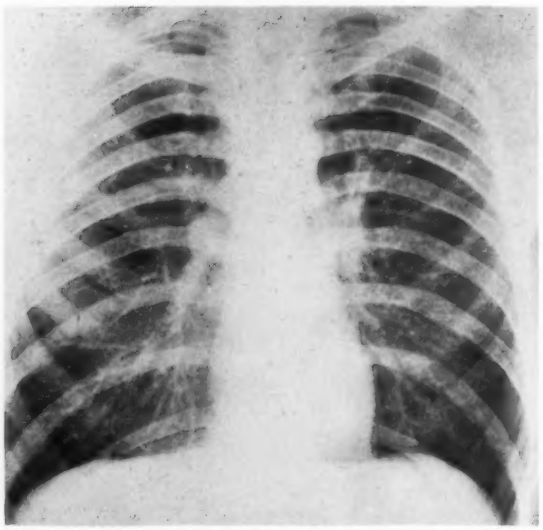

FIG. 4. LN_3. Combined linear and small nodular deposits diffusely scattered throughout both lungs.

linear and/or minute nodular shadows and the other consisted of similar shadows accompanied by larger confluent opacities.

A tentative classification was adopted. This was based upon certain features of the classifications proposed by United States Public Health Service in 1935,[8] Pneumoconiosis Research Unit in 1948,[5] International Labor Organization in 1950,[9] and Smart and Anderson in 1952.[10] Utilizing the technique suggested by Yerushalmy and co-workers[12] to test the applicability of this proposed classification, the 869 pairs of roentgenograms were interpreted independently by each of the radiologists without benefit of any clinical information. Subsequently, in conference, the radiology panel reviewed: (1) all cases in which a difference of classification was recorded by any of the interpreters, and (2) approximately 100 chest roentgenograms which had been interpreted as "normal" by all of the observers. The initial interpretations of the above cases were not known to any of the panel during the review conference. If unanimity of interpretation was not agreed upon, each dissent was recorded. Two subsequent roentgenographic interpretations and review conferences were conducted in a like manner at several month intervals.

In the initial classification of the roentgenograms, an attempt was made to differentially quantitate both the abnormal linear or reticular deposits and the nodular opacities in an area of pulmonary involvement. From the comparisons of the several successive interpretations, it became apparent that the differentiation of the two is often impossible and that the changes are usually coexistent. In the final classification, therefore, linear and nodular manifestations were combined into one category. It may be argued that this arbitrary single category of "linear-nodular" is an oversimplification. However, statistical analyses revealed great intraobserver and interobserver error in interpretations in which linear and nodular changes were classified separately. The formulation of a classification for the coalescent states of the disease presented somewhat less of a problem.

It was also found necessary to include categories to indicate the questionable existence of both linear-nodular and confluent changes. Some of the linear-nodular shadows were particularly difficult to interpret. The roentgenographic pattern and the density of these shadows are such that in some individuals, particularly the obese, it was difficult, if not impossible, to decide whether the chest roentgenogram was "normal" or showed fine but widespread

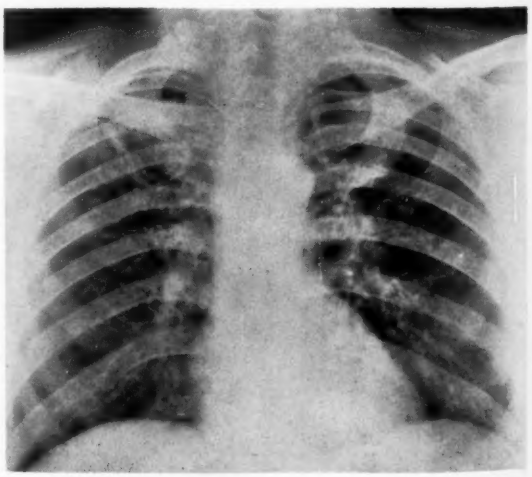

FIG. 5. $LN_3\,C_2$. Scattered linear and nodular deposits in the upper halves of both lungs with a small confluent lesion in the right first anterior interspace.

simple pneumoconiosis. Another source of error was the differentiation between early confluent change of diatomite pneumoconiosis and tuberculosis. These problems cannot be overemphasized, and point to the great need for consistently high quality roentgenograms, experienced radiologists and multiple interpretations.

CLASSIFICATION

The classification was based upon the total *area* of pulmonary involvement by linear-nodular densities and/or conglomerate fibrosis. After careful consideration it was decided not to classify either nodule size or concentration.

The letters "LN" were used to denote linear and/or nodular changes since consistent differentiation between these changes in the simple phase of the disease could not be accomplished. The letter "C" was used to indicate conglomerate or coalescent fibrosis. The complete proposed classification follows.

LN_1 The pulmonary structure pattern is suggestive of linear-nodular changes beyond what is considered normal or average for the given age.

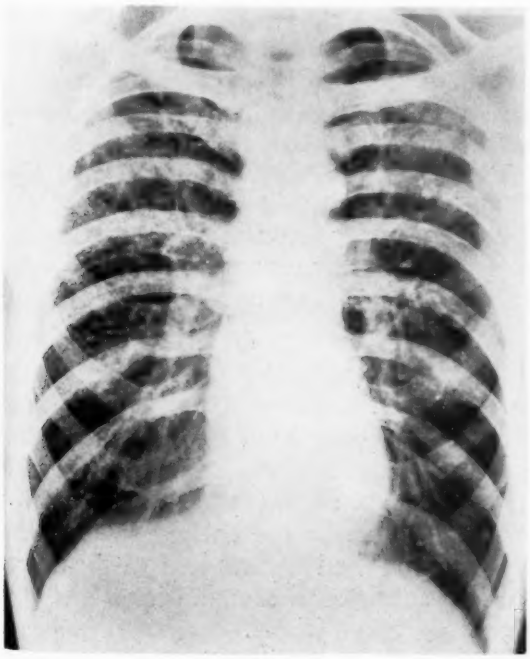

Fig. 6. LN_3 C_3. Numerous nodular and linear densities throughout most of both lungs with early confluence in both upper lobes.

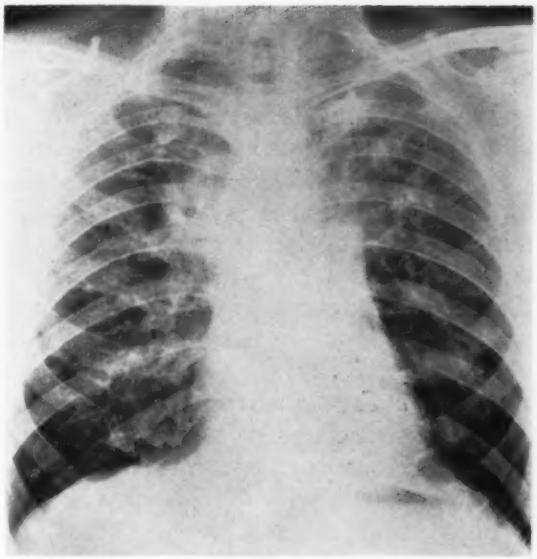

Fig. 7. LN_3 C_4. Profuse linear changes as well as scattered nodules in both lungs with a large confluent mass adjacent to the right superior mediastinum, early confluence of the left upper lobe, emphysema at the left base and marked hilar distortion.

LN_2 Definite abnormal linear-nodular changes extending over an area equivalent to one lung field or less.

LN_3 Definite abnormal linear-nodular changes extending over an area equivalent to more than one lung field.

C_1 Suggestive confluent opacities, superimposed on definite linear-nodular changes.

C_2 Definite confluent opacities, superimposed on definite linear-nodular densities, extending over a total area less than the equivalent of three anterior rib interspaces.

C_3 Definite confluent opacties extending over a total area, the equivalent of three or more anterior rib interspaces but not greater than the equivalent of one hemithorax. A minor degree of mediastinal and hilar distortion may be present.

C_4 Massive confluent opacities over an area greater than the equivalent of one hemithorax, or with gross distortion of the hili, heart, trachea or diaphragm.

ROENTGENOGRAPHIC CHARACTERISTICS

Diatomite pneumoconiosis is characterized roentgenographically by fine linear and/or minute nodular shadows, either or both of which may be accompanied by conglomerate fibrosis. The earliest stage of the uncomplicated form of the disease is more frequently visible in the superior halves of both lung fields below the levels of the clavicles. Most commonly, both linear and nodular shadows are seen in the same involved area. Early the linear changes are virtually indistinguishable from so-called increased bronchovascular markings. The nodules in diatomite pneumoconiosis tend to remain small, only occasionally becoming more than 1–2 mm. in diameter. The simple phase of the disease progresses predominantly by an increase in the apparent number rather than the size of the nodules, often producing a fine sandpaper appearance. The nodules are of low contrast with respect to the surrounding tissue which accounts for the difficulty in demonstrating these shadows roentgenographically early in the disease. They rarely attain the density or size of the nodules often seen in quartz silicosis.

Noteworthy, by their absence, are the calcifications frequently seen in the nodules and the hilar "egg shell" calcifications of quartz silicosis. It is also of considerable interest that in none of this group was there demonstrable mediastinal or hilar lymphadenopathy.

In the early confluent stage of diatomite pneumoconiosis, the linear and nodular changes in both upper lung fields become more apparent due to (1) minimal enlargement of the densities, and (2) contraction and approximation of these densities to each other. These "infiltrations," early, present indistinct margins and are nonhomogeneous. As the process progresses, with or without continued dust exposure, the ill-defined coalescent lesions gradually enlarge into more circumscribed and homogeneous densities. The coalescent lesions predominate in the upper lobes or apices of the lower lobes of both lungs. There is no predilection for either lung. No calcifications were seen in the coalescent areas in any of our cases.

It is also of interest that lobar atelectasis can simulate the coalescent lesion. In one of the cases studied at autopsy by Carnes,[3] the so-called coalescent lesions in both upper lung fields were in fact completely atelectatic upper lobes of both lungs with complete stenosis of both major upper lobe bronchi.

As contraction of the lesions occurs, there is frequently a pseudo-clearing of the lower lung fields due primarily to compensatory emphysema rather than to true clearing of the disease process. Although pulmonary cavitation was not seen in the workers participating in this survey, several of the cases reviewed by Carnes showed both necrosis and cavitation with and without coexistent tuberculosis.

Enlargement of the coalescent masses is usually accompanied by mediastinal, hilar and diaphragmatic distortion and progressive emphysema. Pulmonary and mediastinal distortion may occur in the presence of relatively small areas of confluence. Carnes' cases revealed spontaneous pneumothorax and cor pulmonale as relatively frequent complications in the terminal phases of the disease. No instances of spontaneous pneumothorax were encountered in this study.

RESULTS OF ROENTGENOGRAPHIC INTERPRETATIONS

Of the 869 employees studied in the 1953–1954 survey (Table II), 78 workers or 9.0 per cent had doubtful evidence of pneumoconiosis. Another group of 78 individuals or 9.0 per cent had definite roentgenographic evidence of diatomite pneumoconiosis, and 32 of these (41 per cent) had confluent disease. Of the entire group of employees, 84 had incomplete medical histories and physical examinations. The percentages of positive roentgenograms was not altered significantly by the deletion of these individuals from the statistical analysis. Another group of 47 employees was

TABLE II

ROENTGENOGRAPHIC INCIDENCE OF PNEUMOCONIOSIS IN DIATOMITE WORKERS BY STUDY GROUP

Interpretation of Chest Roentgenograms	Study Group					
	All Workers in Study		Workers with Complete Examination		Workers with History of No Dust Exposure Prior to Entering Diatomite Industry	
	No.	Per Cent	No.	Per Cent	No.	Per Cent
Normal O	713	82.0	642	81.8	612	83.0
Doubtful LN_1	78	9.0	69	8.8	58	7.9
Definite:	78	9.0	74	9.4	68	9.1
Simple LN_2, LN_3	29	3.3	28	3.6	24	3.2
Simple LN_2, C_1, LN_3, C_1	17	2.0	16	2.0	16	2.1
Confluent C_2, C_3, C_4	32	3.7	30	3.8	28	3.8
Total	869	100.0	785	100.0	738	100.0

also excluded from analysis since their occupational histories indicated that prior employment had involved exposure to other dusts for a period in excess of one year. Although the abnormal roentgenograms of these individuals with prior dust exposures were not characteristic of other pneumoconioses, exclusion from the statistical analysis appeared to be indicated. Again, no significant difference in the percentage of positive roentgenograms resulted from this deletion.

The work assignments of each employee were categorized as quarry, mill, or office and maintenance. Each individual's total employment was described in terms of the approximate number of years in each type of activity. Figure 1 presents the distribution and correlation of the interpretation of the chest roentgenograms relative to the years of employment in each activity. All workers with other dust exposures and incomplete histories and physical examinations were excluded from the statistical analysis.

The major occupational hazard was in the mills. Of the employees with five years or less of employment in this activity alone, only 0.4 per cent had definite simple pneumoconiosis, and none had confluent disease. However, of those who were employed in the mills only for more than five years, 17.0 per cent had simple pneumoconiosis and 23.2 per cent had confluent disease.

In contrast, no employee with a work history of five years or less in the quarry alone had definite evidence of pneumoconiosis. However, 40 per cent of those employed in the quarry for more than five

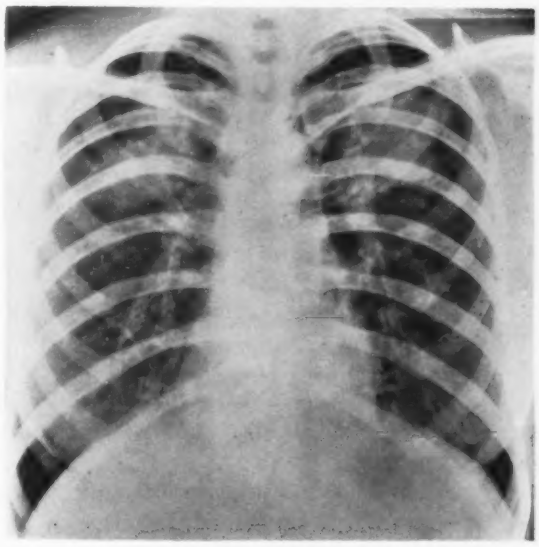

FIG. 8. LN_2 C_4. Large confluent masses bilaterally with surrounding emphysema and distortion of the hili. A few linear and nodular densities are also present.

years showed doubtful changes. No cases of confluent disease were observed in the quarry workers, irrespective of the number of years of employment in this activity.

TUBERCULOSIS

The suspected relationship between pulmonary tuberculosis and many of the silicoses suggested the need to determine whether there might be a similar relationship with diatomite pneumoconiosis; particularly since there were a number of employees who demonstrated pulmonary changes indistinguishable from the linear infiltrates commonly seen in tuberculosis. Correlative analyses were made among those employees with positive reaction to 0.0001 mg. purified protein derivative and those with roentgen evidence of diatomite pneumoconiosis, particularly those with confluent disease. The total percentage of positive reactors was 33.7 per cent. There were 43.6 per cent positive reactors among all those showing suspicious or definite roentgen evidence of pneumoconiosis and 42.9 per cent in the group with coalescent disease. These indeterminate results, coupled with the small sampling, indicate that this study produced no statistically significant evidence of the relationship between these two diseases. It is worthy of note that 57 per cent of the 28 cases with confluent pneumoconiosis had negative tuberculin reactions. These figures probably do not reflect the true prevalence of tuberculosis since some workers who developed active tuberculosis have been known to have left the industry.

SUMMARY

1. The roentgenographic changes of diatomite pneumoconiosis are described and a new classification proposed.

2. Roentgenographic examination of 869 diatomite workers showed definite changes consistent with pneumoconiosis in 78 individuals (9 per cent). Of these, 32 (41 per cent) had confluent disease. An additional 9 per cent of the employees had doubtful evidence of pneumoconiosis.

3. An interrelationship between diatomaceous earth pneumoconiosis and tuberculosis has not been established.

George Jacobson, M.D.
1200 North State Street
Los Angeles 33, California

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PULMONARY HISTIOCYTOSIS X*

A CASE REPORT

By EUGENE C. CRISLER, M.D., JOHN R. DURANT, M.D., *and* THOMAS M. PARKER, M.D.
CHARLESTON, SOUTH CAROLINA

ALTHOUGH reports in the literature indicated a growing awareness of the fact that Schüller-Christian disease and Letterer-Siwe disease were clinical variations of the same basic process, it remained for Jaffe and Lichtenstein[3] in 1944 to add the most benign variant, eosinophilic granuloma of bone, and to demonstrate a pathologic relationship in all three disorders. Later they proposed the term "histiocytosis X" as an appropriate designation for this triology to emphasize the histiocytic proliferation common to all. Since that time numerous articles appeared dealing with the many variants seen clinically; and many etiologic hypotheses have been proposed. Among these variants is one in which the process involves the lungs to a greater or lesser extent. Some of these cases have had concomitant bone lesions, but others were distinguished by pulmonary involvement alone. Documented cases of this variant of histiocytosis X (in which pulmonary biopsy was obtained) were first recorded by Farinacci *et al.*[4] in 1951, and since that year have been reported in increasing number. The purpose of this paper is to reemphasize the place of this entity in the differential diagnosis of miliary pulmonary infiltrations by presenting another such case.

REPORT OF A CASE

This twenty-one year old white male was admitted to the United States Naval Hospital, Charleston, South Carolina, on August 17, 1959 because of pain in the left knee due to traumatic ligamentous injury. His only other complaint was a nonproductive cough of one year's duration. He denied other cardiorespiratory symptoms as well as chills and fever. Admission chest roentgenograms (Fig. 1, *A* and *B*) revealed a widely disseminated, finely nodular

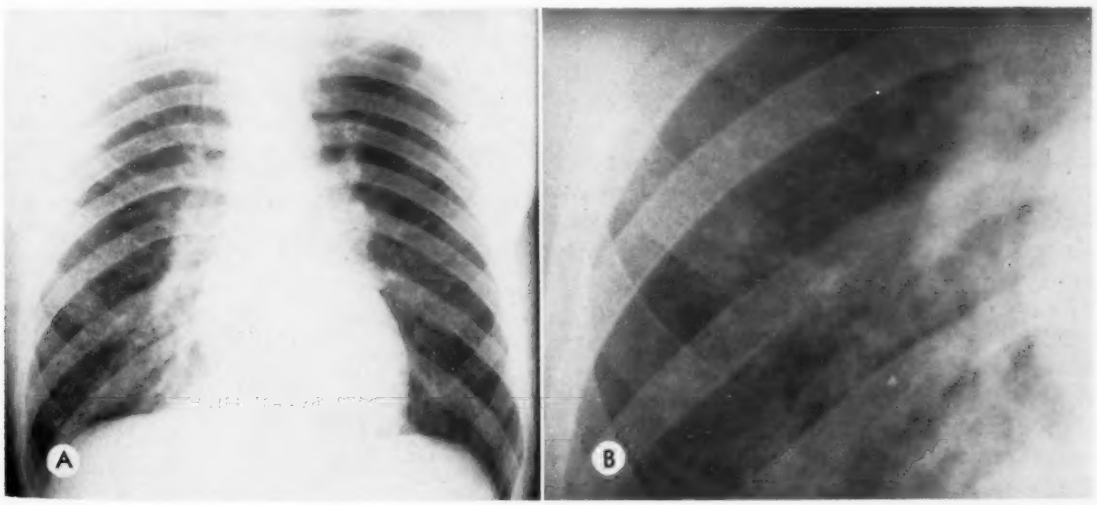

FIG. 1. (*A*) Posteroanterior roentgenogram of the chest shows a widely disseminated, finely nodular infiltration throughout both lung fields. Several small areas of confluence of the nodules are present but no frank consolidation. (*B*) A slightly magnified view of the right middle lung field demonstrates the finely reticulated background as well as the nodular infiltration.

* From the Departments of Radiology, Medicine, and Pathology of the United States Naval Hospital, Charleston, South Carolina.
The opinions expressed are those of the authors and do not necessarily represent the opinions of the United States Naval Hospital, Charleston, South Carolina, or the Department of the Navy.

infiltration of both lungs. Because of these findings he was transferred to the medical service for investigation.

Physical examination revealed a young white male in no distress. There was evidence of instability of the left knee joint. The firm tip of the spleen was palpated by at least two observers; otherwise, the examination was negative. The past history was noncontributory. A chest roentgenogram taken on induction into the Air Force in January, 1957 was normal.

Laboratory studies showed the white blood cell count, hemoglobin, hematocrit, uninalysis, serology, calcium, phosphorus, albumin, globulin and alkaline phosphatase to be within normal range. A bromsulphalein test revealed 7 per cent retention in forty-five minutes. An electrocardiogram was normal. Cultures of the sputum and bronchial washings for bacterial pathogens as well as fungi and acid fast bacilli were not significant. Purified protein derivative tests #1 and #2 were negative as were skin tests with histoplasmin, coccidioidin and blastomycin. Pulmonary function tests consisting of vital capacity, timed vital capacity, and maximum breathing capacity were within normal limits. Blood gas studies were as follows: oxygen saturation at rest 84.2 per cent with an increase to 91.4 per cent after exercise and to 95.3 per cent after breathing 100 per cent oxygen for fifteen minutes. These results were interpreted to indicate a mild degree of physiologic pulmonary arteriovenous shunting and to be incompatible with an alveolocapillary block. A complete bone survey was negative. Bronchoscopy disclosed a diffuse hyperemia of the mucosa but was otherwise normal. A supraclavicular lymph node biopsy showed only reactive hyperplasia.

On October 5, 1959 an open pulmonary biopsy was performed under general anesthesia. The lung was described as grossly infiltrated with very fine 2–4 mm. nodules. The pleura was uninvolved by the process, and there was no evidence of cyst formation. A biopsy of the right lung was obtained at this time and handled under sterile technique.

The specimen measured 1 cm. in diameter and was finely nodular upon palpation. Its bisected surface showed grayish 3 mm. nodules, one of which was concisely outlined, although the others were less sharply defined (Fig. 2). One half of the specimen was emulsified with sterile broth, and aliquots of the mixture were used to inoculate blood agar, EMB agar, chocolate blood agar and thioglycollate broth. Slants of Sabouraud's agar and Petragnani's medium were also inoculated. Growth was not obtained on any of these media. The remaining half of the specimen was fixed in 10 per cent formalin and routine hematoxylin and eosin stained sections were prepared from the block. Examination of these sections disclosed focal accumulations of histiocytes and eosinophils (Fig. 3), typical of eosinophilic granuloma. In addition, there was interalveolar septal fibrosis with prominent epithelization of these thickened septa. In some areas the fibrosis was extremely marked and explained some of the nodularity noted grossly. In other foci the thickened septa outlined cystic spaces which adjoined each other in such a way as to give the impression of "honey-combing" on a microscopic scale. Within the areas of active histiocytic proliferation, the process appeared to involve the walls of the small blood vessels (Fig. 4). The total histologic picture was one of histiocytosis X, demonstrating various stages of maturation.

The patient was placed on meticorten, starting with 40 mg. daily in divided doses. This was continued for one month and then gradually decreased over another six weeks because the roentgenographic appearance remained unchanged and because Cushingoid changes were observed. The patient had no symptomatic improvement when last seen in August, 1960.

Comment. This is a rather characteristic case of pulmonary histiocytosis X. The patient is a young white male whose disease

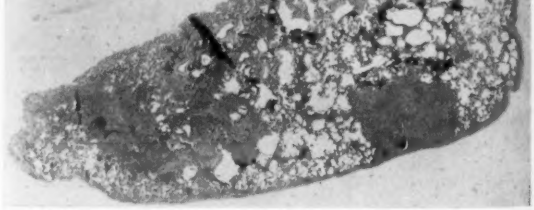

FIG. 2. Low power macrophotograph of entire tissue section. Note subpleural nodule at lower right and extensive fibrosis at left. Interalveolar septal fibrosis with emphysema can be seen above the subpleural nodule. (H. & E. ×18.)

was discovered on routine admission chest roentgenograms and whose symptomatology consists only of cough. There is no obvious explanation for the palpable spleen which has not been a common finding in other reported cases. Perhaps this indicates that the disease process is not limited to the lung. On the other hand, the failure of the spleen to continue to enlarge as well as the unchanging cough and roentgenographic findings suggest lack of progression of the process. No obvious benefit was derived from corticosteroid therapy, which adds further support to the thesis of Timmes *et al.*[11] that this form of treatment has little to offer in pulmonary histiocytosis X.

DISCUSSION

Pulmonary histiocytosis X may involve the lungs as part of a generalized process, as the major manifestation of a disease occurring in several different organs or as the only manifestation of the disorder. Recently, Nadeau *et al.*[8] found in the literature 21 cases with disease originating in the lungs and added 7 of their own. Not included in this review were the 6 cases of Timmes *et al.*,[11] the case of Mengis,[7] and one case of Pagan-Carlo and Haley.[9] Thus the total number of reported cases with pulmonary involvement as the sole or major manifestation of the disease, including the case herein reported, is approximately 37. It is to be expected that, as open pulmonary biopsy becomes more commonly used, many more instances of this process will be uncovered.

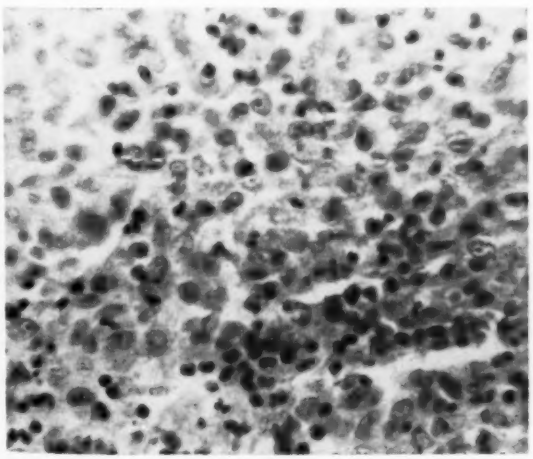

Fig. 3. Photomicrograph of subpleural nodule. Note the pale nuclei of the histiocytes at the upper left, and the dark nuclei of the eosinophils below and to the right. (H. & E.×430.)

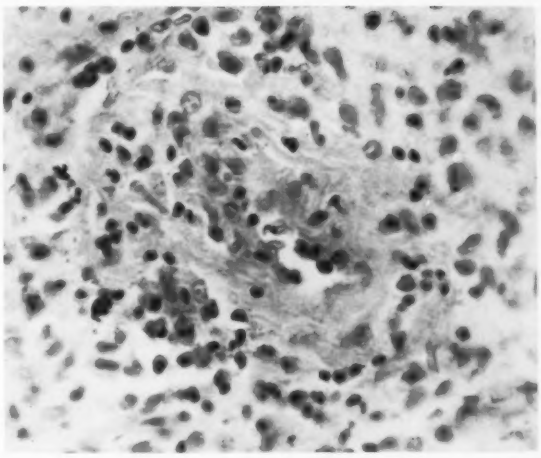

Fig. 4. Arteriolar involvement within the lesion. Note the presence of eosinophils within the vessel wall and the apparent dissolution of the latter. (H. & E.×430.)

The disease appears to occur primarily in young and middle aged adult males. Since most of the early reports originated from military and Veterans Administration hospitals, it was assumed that the preponderance of males in these series was due mainly to the selected population; however, the report of Nadeau *et al.*,[8] originating from the Mayo Clinic, included 6 males and only 1 female, indicating that there may be a true predilection of this disorder for the male.

Symptoms are often mild and may not concern the patient, so that the diagnostic studies are usually undertaken because of an abnormal routine chest roentgenogram. However, most of the patients have complained of a dry or slightly productive cough. Dyspnea, low grade fever, weight loss, fatigue and mild constitutional symptoms are occasionally encountered.

Usually the physical examination is unrevealing and lymphadenopathy is not a feature. Examination of the chest is generally normal unless pulmonary fibrosis and emphysema have resulted or pneumothorax

is present. Rarely, wheezes and rales have been noted.

Laboratory studies are equally unrewarding. A wide variety of physical, chemical and pathologic studies have been undertaken in these patients. The white blood cell count and differential are usually normal, although mild (and probably insignificant) eosinophilia has been encountered. Albumin-globulin ratios are occasionally altered. Bronchoscopy is either normal or reveals hyperemia of the mucosa. In general, cultures of sputum, blood, gastric washings, and bronchial secretions have been noncontributory, as have skin tests for tuberculosis and the commun fungal diseases. Bone marrow, liver, and scalene lymph node biopsies have not helped in the diagnosis.

Pulmonary function studies have yielded varied results. Two of Nadeau and coworkers'[8] patients had evidence of fibrotic and obstructive disease, and one was normal. Timmes *et al.*[11] performed extensive pulmonary function studies on all 6 of their patients with pulmonary involvement. They found a slightly reduced vital capacity in 2, minimal slowing of the timed vital capacity in all, and a normal maximal breathing capacity. The commonly used spirogram was thus virtually normal in all their cases as it was in the case of Mengis.[7] On the other hand, residual volumes and the residual volume to total lung capacity ratio were elevated in all their patients, and the compliance was reduced in 4, indicating overdistention of the lungs. Blood gas studies were normal or nearly so in all of their cases.

Two distinct roentgenographic patterns have been described: (1) a generalized, disseminated, nodular, granulomatous infiltration of both lungs and (2) a reticulated background of diffuse interstitial fibrosis. The case herein recorded was no exception. The admission chest roentgenogram showed a very fine, diffuse nodularity disseminated through both lungs. Also found were a notable absence of hilar lymphadenopathy, consolidative parenchymal infiltration, and pleuritic reaction. This appearance remained unaltered during the ten month follow-up.

With more than eighty lesions producing a disseminated miliary appearance in the lungs, it seems unlikely that the radiologist would be successful in offering a specific diagnosis when confronted with the roentgenographic picture of eosinophilic granuloma of the lung. However, absence of consolidative infiltrations, acute pleuritic reactions, and cavitary disease correlated with the clinical picture of a healthy patient tends to eliminate most of the acute bacterial and mycotic processes. Careful examination of the chest roentgenogram shows the infiltration to be as closely dispersed in the apical regions as in the bases, if allowance is made for the increased pulmonary volume at this location. This tends to eliminate most, if not all, of the pneumoconioses, since they generally appear most prominent in the basilar regions of the lungs, which receive the greatest aeration. The absence of hilar lymphadenopathy, obvious lymphangitic and perivascular reaction further narrow the probabilities, tending to eliminate sarcoidosis, other granulomatous infiltrates, various malignant processes, and collagen diseases.

In the experience of others, a "honeycomb" pattern has been frequently seen. In the opinion of at least one author, the association of this "honey-comb" pattern with spontaneous pneumothorax should suggest this disease. Although such a combination was not present in our case, this diagnostic feature is worthy of note.

In the final analysis, the precise diagnosis rests upon thoracotomy with pulmonary biopsy. The histopathologic appearance is distinctive and diagnostic; it has been reviewed by Auld[2] in a report of 5 personally studied cases as well as those previously reported in the literature. In general, it includes focal accumulations of histiocytes and eosinophils, areas of fibrosis, and cystic formations. Auld draws attention to vascular changes present in these nodules; he noted fibrinoid degenera-

tion of the arteriolar walls with actual invasion of the vascular structures by histiocytes and eosinophils. He further noted the presence of emphysematous changes in the pulmonary parenchyma distant from the involved areas. It is generally believed that the active stage of the process is characterized by the cellular histiocytic nodule, and that maturation of the nodule results in, at first, interstitial fibrosis, and later a more generalized fibrosis. By-products of this fibrotic change include cyst formation which may be of such degree as to merit the term "honey-combing."

The etiology of this disorder is unknown. Although many hypotheses have been advanced, none of them have been supported by realistic confirmatory evidence. A recent approach to the problem is from the standpoint of hypersensitivity. Auld[2] cites the presence of arteriolitis and fibrinoid degeneration within the involved areas as evidence of an allergic mechanism basic to the disease. He compares the process, then, with periarteritis nodosa and Löffler's syndrome, considering all three conditions to share a basic etiology in hypersensitivity. Despite this promising clue, a great deal remains to be learned of the underlying stimuli of this disorder.

The prognosis is uncertain, although in many cases it appears to be good. Three serious complications are encountered. Because of the cyst formation which may occur, pneumothorax occasionally results and may be recurrent or even bilateral. Diabetes insipidus may appear subsequent to the discovery of the chest lesion. Finally, pulmonary fibrosis and emphysema with chronic cor pulmonale may eventuate. On the other hand, spontaneous remission is frequently encountered, as is lack of progression of signs and symptoms. Occasionally, the disease may run a fulminating course with death resulting in a short time.

There is no agreement as to treatment. In the past radiation therapy was utilized because of the response of the bony form of the disease to this form of treatment. It appears to be largely abandoned because of the lack of responsiveness and the consideration that since fibrosis may be the result of the granulomatous process it does not appear logical to apply a form of treatment which in itself may induce fibrosis. Adrenal cortical steroids are the most common current agents in use. Nadeau *et al.*[8] found 11 cases treated with steroids and state that most were improved, although only 2 completely cleared. Five of their 7 patients were given steroids. Three developed roentgenographic evidence of clearing, one was followed for only six weeks with improvement in pulmonary function, and one improved although follow-up roentgenograms were not available. Mengis'[7] patient noted improvement in symptoms before the initiation of steroid therapy, but no change in the roentgenograms was observed after nine weeks, and treatment was discontinued. Livingston's[6] case did not respond to one course of treatment and then appeared to respond to a second course given six months later. On the other hand, Timmes *et al.*[11] noted improvement in 5 of their 6 cases with no therapy whatsoever, and no response in the one case in which steroids were given. They do not believe steroid therapy is indicated unless there is evidence of continuing progression of the disease, whereas Nadeau *et al.*[8] believe that a course of steroid therapy is indicated for every patient.

We have noted no improvement in our patient who was given sufficient steroid therapy to produce changes of the Cushing type. It seems likely to us that, since evaluation of treatment is so difficult and since spontaneous remission is so common, it is unlikely that steroid treatment has really been of benefit and that the good results are frequently coincidental. Nevertheless, there is good theoretic basis for the administration of an agent which inhibits fibrosis, and so further evaluation of the steroids is indicated.

SUMMARY AND CONCLUSIONS

1. An additional case of pulmonary histiocytosis X is reported with the intent of

re-emphasizing the place of this entity in the differential diagnosis of miliary pulmonary infiltrations.

2. The case presented is a characteristic one. An admission chest roentgenogram revealed diffuse, nodular, miliary infiltration in a young white adult male in good health with a chronic cough. The diagnosis was established by pulmonary biopsy. The disease has neither progressed nor regressed despite a course of steroid therapy.

Eugene C. Crisler, M.D.
Department of Radiology
United States Naval Hospital
Charleston, South Carolina

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EXCAVATING PULMONARY METASTASES*

By GERALD D. DODD, M.D., *and* JAMES J. BOYLE, M.D.†
HOUSTON, TEXAS

WHILE spontaneous cavitation of malignant primary tumors of the lung has been widely reported, it is regarded as unusual in metastatic pulmonary nodules. A search of the literature has yielded 43 cases of the latter, the majority having been reported as incidental observations or differential diagnostic problems. These cases are summarized in Table 1. Examples of necrosing pulmonary lymphoblastomas have not been included since the propriety of designating these as metastatic deposits is questionable.

In most reports dealing with excavating pulmonary tumors, local circulatory inadequacy is cited as the primary cause. Usu-

TABLE I

REPORTED CASES OF ROENTGENOGRAPHICALLY DETECTED NECROTIZING PULMONARY METASTASES

Author	No. of Cases	Site of Primary Growth	Histopathology	No. of Metastases
1. Bristowe[2]	1	Pharynx	Squamous cell carcinoma	———
2. Farrell[7]	1	Undetermined	Sarcoma	Multiple
3. Dolgoff and Hansen[5]	1	Bone	Ewing's sarcoma	Multiple
4. Katzev and Bass[11]	1	Colon	Adenocarcinoma	Multiple
5. Salzman, Reid and Ogura[29]	2	a. Testes	a. Seminoma	Multiple
		b. Pancreas	b. Ductal adenocarcinoma	Multiple
6. Minor[23]	4	a. Urinary Bladder	a. Squamous cell carcinoma	a. ———
		b. 3 cases with no primary stated	b. ———	b. ———
7. Wigh and Gilmore[37]	1	Uterine cervix	Squamous cell carcinoma	Solitary
8. Rigler[27]	1	Bone	*Osteogenic sarcoma	Multiple
9. La Foret and La Foret[13]	6	a. Mediastinum	a. Teratocarcinoma	a. ———
		b. 5 cases, breast or pancreas	b. Adenocarcinoma	b. ———
10. Seaman and Arneson[30]	1	Uterine cervix	Squamous cell carcinoma	Solitary
11. Lichtenstein[18]	1	Bone	Osteogenic sarcoma	Multiple
12. Meyers and Sala[22]	1	Lung	Squamous cell carcinoma	Multiple
13. Wellens[36]	2	a. Lung	Squamous cell carcinoma	a. ———
		b. Penis	Squamous cell carcinoma	b. ———
14. Deck and Sherman[4]	19	a. Urinary bladder	a. Squamous cell carcinoma	a. ———
		b. Lung	b. ———	b. ———
		c. Bone	*c. Osteogenic sarcoma	c. Solitary
		d. Kidney	*d. Wilms' tumor	d. Multiple
		e. 15 cases with no primary stated	e. ———	e. ———
15. Curran and MacCarthy[3]	1	Rectum	Adenocarcinoma	Multiple
Total	43			

* Necroses detected after irradiation of nodules and/or chemotherapy.

* From the Section of Diagnostic Radiology, The University of Texas M. D. Anderson Hospital and Tumor Institute, The Texas Medical Center, Houston, Texas.
† Now at the Department of Radiology, Hahnemann Medical College Hospital, Philadelphia, Pennsylvania.

ally, it is postulated that necrosis results when the size of the tumor exceeds the available blood supply. Other suggested mechanisms are infarction of the regional nutritional vessels by the growing tumor or blockage of a bronchus in the same fashion with subsequent infection and abscess formation distal to the obstruction.

This report was prompted by the relative frequency of cases of excavating pulmonary metastases at M. D. Anderson Hospital and Tumor Institute, many of which were seemingly not explained by the theories noted above. A series of cases was therefore studied in an attempt to determine: (1) the roentgenographic incidence of excavating metastatic pulmonary tumors; (2) the location and histologic type of primary tumors; (3) a mode of pathogenesis; (4) the characteristic roentgenographic criteria, if any; and (5) the feasibility of identifying the site of the primary lesion by the appearance of its metastases. For these purposes, the chest roentgenograms of 6,729 consecutive patients seen between August 1, 1955 and February 1, 1957 were reviewed. Each patient had been referred with at least a tentative diagnosis of neoplastic disease and only those with unequivocal roentgenographic evidence of pulmonary metastases were selected for this study. The distribution of the metastasizing primary tumors is recorded in Table II. No attempt has been made to indicate the frequency of pulmonary metastases with respect to the various primary lesions nor does the presence of metastatic disease in the chest imply that all patients suffered from detectable metastases when first seen. Many in this series developed pulmonary metastases months or years after definitive therapy, but were included since at least one positive chest roentgenogram was made during the eighteen month period.

Initially, the roentgenographic diagnosis of a cavitating pulmonary tumor was based upon the criteria of Wigh and Gilmore:[37] (1) well circumscribed intrapulmonary mass; (2) centrally located cavity; (3) thick, easily defined wall; (4) irregular or actually nodular inner wall; (5) absence of parenchymal inflammatory change elsewhere; and (6) the presence of additional metastatic lesions (Fig. 1, *A* and *B*). How-

TABLE II

DISTRIBUTION OF PRIMARY TUMORS WITH PULMONARY METASTASES

Primary Site	No. of Cases	No. Necrotizing
1. *Head and Neck*		
a. Lip	3	0
b. Mouth	3	1
c. Tongue	3	0
d. Pharynx	4	2
e. Larynx	11	1
f. Thyroid	21	0
g. Parotid gland	4	0
h. Miscellaneous	5	0
	54	4
2. *Gastrointestinal Tract*		
a. Esophagus	5	0
b. Stomach	3	0
c. Colon	16	3
d. Liver	1	0
e. Pancreas	2	0
	27	3
3. *Genitourinary Tract*		
a. Kidney	15	0
b. Bladder	6	1
c. Ureters	2	0
d. Prostate	4	0
e. Corpus	7	0
f. Cervix	30	4
g. Vulva	1	1
h. Ovary	9	0
i. Testes	8	0
	82	6
4. *Breast*	94	2
5. *Lung*	20	0
6. *Miscellaneous*		
a. Skin	8	1
b. Melanoma	30	0
c. Soft tissue sarcomas	11	0
d. Synoviomas	3	0
e. Bone		
Osteogenic sarcoma	11	0
Ewing's sarcoma	8	0
f. Lymphomas	12	0
g. Unknown primary	38	0
	121	1

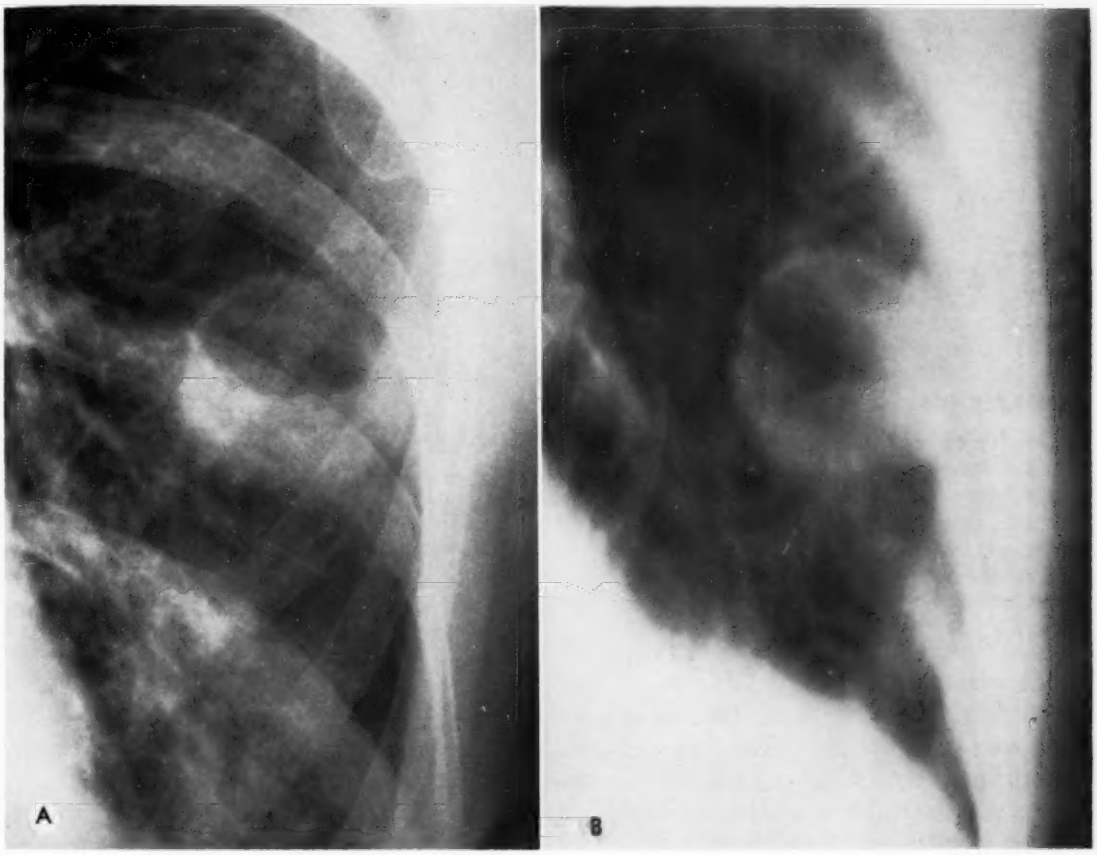

Fig. 1. Solitary excavating squamous cell carcinoma of lingula in a sixty-nine year old white female with previously treated squamous cell tumor of cervix. Histology was inconclusive as to whether this was a pulmonary primary tumor or metastasis. (*A*) Conventional erect posteroanterior roentgenogram of chest. Air-fluid level is present. (*B*) Laminagram in recumbent anteroposterior projection demonstrating the criteria of Wigh and Gilmore[37] for the diagnosis of excavating pulmonary neoplasms.

ever, so-called "ring shadows" were soon encountered, the walls of which were proved to be of neoplastic origin but so thin that, at times, all of the foregoing criteria did not apply (Fig. 2, *A* and *B*; 3, *A* and *B*; 4, *A* and *B*; 6, *A* and *B*; 7, *A* and *B*; and 8, *A* and *B*). In such instances, a stringent analysis of the composite shadows of the area was carried out. If any part of the ring wall could be considered vascular, pleural or of other extraneous origin, the diagnosis of cavitation was considered equivocal and the case discarded for purposes of this study.

In each instance the histopathology of the primary tumor has been carefully restudied. Where possible, proof of the neoplastic nature of the cavity has been obtained by autopsy or pulmonary resection and the histopathology of the metastatic lesion related to the primary tumor. In cases where this has not been feasible, reliance has been placed on roentgenographic criteria, serial examinations, clinical evidence of metastatic deposits elsewhere, and the absence of clinical or laboratory evidence of pulmonary inflammatory disease.

The incidence of cavitating bronchogenic carcinoma was also determined for comparative purposes.

INCIDENCE

Roentgenographically detectable cavitation was found in 9 per cent of primary lung tumors and 4 per cent of pulmonary metas-

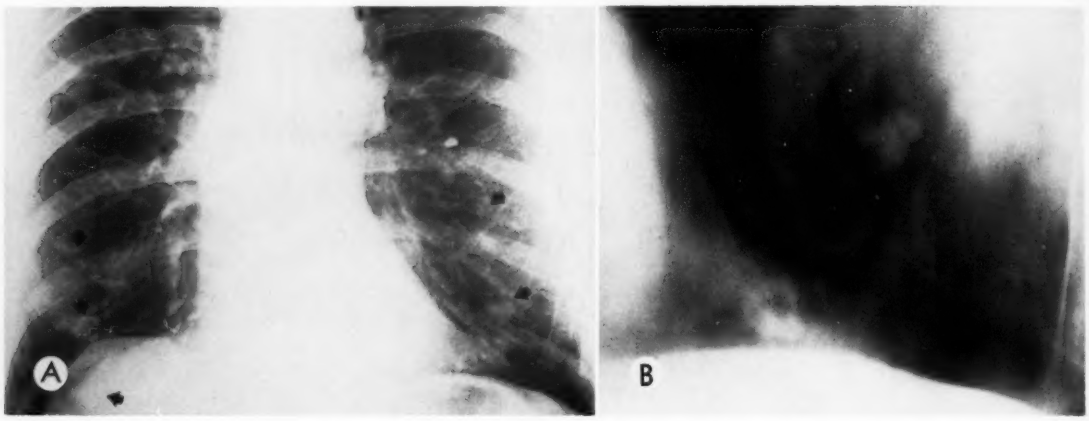

FIG. 2. Multiple excavating pulmonary metastases in a seventy-eight year old white male with Grade III squamous cell carcinoma of the ear. The tumor has widely infiltrated the parotid gland and the regional cervical lymph nodes. A marked tendency to central necrosis was evident in all biopsy specimens. (*A*) "Ring shadows" as well as apparently solid nodules are scattered throughout the chest. The largest nodule (right lower lobe) measures 1.5 cm. in diameter and shows extensive excavation. (*B*) Laminagram of left base showing neoplastic characteristics of a cavity in a 1.2 cm. nodule just above the diaphragm. The second metastatic deposit appears solid, but later showed excavation.

tases in this study. An additional 7 excavating neoplasms could not be placed in either category since all were solitary lesions of squamous cell origin, arising in patients with primary squamous cell carcinoma elsewhere. In all probability, the incidence of central excavation in metastases is higher than the figures indicate. An additional 20 cases were discarded in the absence of unequivocal roentgenographic proof of cavitation and no cases were included in which excavation was detected following chemotherapy or local roentgen therapy to the metastases. The results of the analysis are recorded in Table III.

HISTOLOGIC TYPES

Eleven, or 69 per cent, of the multiple excavating metastatic nodules were of squamous cell origin. All of the excavating bronchogenic carcinomas were of this cell type, a finding in agreement with other published series. The remainder of the metastatic group (5) were adenocarcinomas. Three originated in the colon and 2 in the female breast. The tendency of the pulmonary metastases of adenocarcinoma of the colon to excavate is emphasized when it is noted that the 3 cases in this series occurred in but 16 patients as contrasted to 2 examples in 94 patients with carcinoma of the breast. Le May[15] has also observed 4 cases occurring with carcinoma of the colon and Curran and MacCarthy[3] have recently reported a case.

Since the number of excavating metastases in the series is relatively small, we have attempted to confirm this distribution by investigation of material accumulated since February 1, 1957. The additional cases do not represent an exhaustive review of all metastatic disease as in the initial group, but are those routinely indexed in the course of daily film interpretation. Twelve examples of unequivocal excavating metastases were encountered; 9 of squamous or transitional cell type, 2 adenocarcinomas (breast and corpus uteri) and 1 melanoma. As in the previous group, almost an equal number were discarded since the roentgen findings were equivocal and 2 solitary lesions were listed which could not be differentiated from primary bronchogenic carcinoma. The locations of the primary tumors paralleled those of the first group studied. Analysis of the over-all distribution of tumors in this institution did not indicate a sufficient variation from those of the average community to invalidate these findings.[21]

TABLE III

RESULTS OF ANALYSIS OF 6,729 CONSECUTIVE CASES

A. Cases Reviewed (consecutive)		6,729
a. Malignant tumors of the lung		574 or 8.5% of total cases
1. Primary tumors of lung		176 or 2.6% of total cases
2. Metastatic tumors of lung		398 or 5.9% of total cases
B. Cases of Excavating Tumors		37
a. Bronchogenic carcinoma		16 or 9.1% of primary tumors
b. Metastatic tumors		16 or 4% of metastatic tumors
c. Primary vs. solitary metastatic tumors		7 or 17.9% of excavating tumors
C. Multiple Excavating Metastases		
Site of Primary	No. of Cases	Cell Type
a. Pharyngo-larynx	4	Squamous
b. Female genitalia	5	Squamous
c. Skin	1	Squamous
d. Urinary bladder	1	Transitional
e. Colon	3	Adenocarcinoma
f. Breast	2	Adenocarcinoma
D. Excavating Primary vs. Solitary Metastatic Tumors		
Site of Primary	No. of Cases	Cell Type
a. Uterine cervix	3	Squamous
b. Pharyngo-larynx	2	Squamous
c. Skin	1	Squamous
d. External genitalia	1	Squamous

PATHOGENESIS

The reasons for the assumption that necrosis in pulmonary tumors is attributable to an inadequate blood supply have been summarized by Willis[38] as follows: (1) the vascular supply of most pulmonary tumors of epithelial origin is richest at the margins; (2) short of actual necrosis, many features indicative of inadequate cellular nutrition or oxygenation are frequently noted microscopically; and (3) degenerative changes are common both at autopsy and microscopically in pulmonary tumors which exceed several centimeters in diameter. Presumably, as the growing tumor outstrips its blood supply, central ischemia occurs with ensuing necrosis. Infection may or may not supervene. Roentgenographically, necrosis becomes evident when communication with a regional bronchus permits expulsion of the necrotic material.

As the review of our series progressed, some doubt was cast upon the complete validity of this explanation by three factors: (1) the extremely small size of many of the necrosing tumors; (2) the thinness (1–2 mm.) and internal smoothness of the walls of many cavities; and (3) the predominance of squamous cell lesions. Discussion of the problem with pathologists also indicated that the majority of central degenerative changes seen at autopsy were of a gelatinous or caseous nature rather than actual cavitation. For these reasons other explanations were sought.

The possibility of implantation of tumor cells by aspiration was considered since many of the primary lesions were located in the head and neck area. It was also postulated that metastases of this type would tend to be less vascular and hence more likely to necrose at an early stage. However, this explanation was largely discarded when it became evident that direct exfoliation of cells into airway was not probable in the majority of our cases and that primary lesions elsewhere in the body resulted in identical forms of cavitating metastatic disease in the lungs. Aspiration spread cannot be entirely dismissed on these grounds,

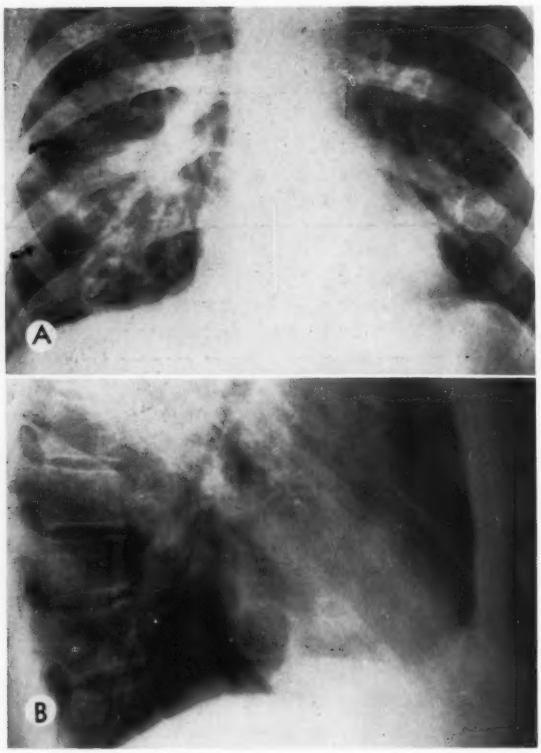

FIG. 3. (*A* and *B*) Multiple excavating pulmonary metastases in a forty-four year old white male with Grade II squamous cell carcinoma of the skin invading the parotid gland and the regional lymph nodes. Microscopically, the tumor showed intracellular keratin and pearl formation; the lymph node metastases were anaplastic with central degeneration. Fluid levels are present in the larger metastases. The arrows in *A* indicate smaller excavating deposits. Note relative uniformity of all wall thicknesses despite the size of the metastases.

but Liebow[17] has described such tumors as largely intrabronchial and polypoid with a relatively small base of attachment. This description did not apply in any of the cases in our series in which resection or autopsy was done and proved cases in the literature are comparatively rare. Willis[38] has pointed out that three factors usually prevent engrafted disease in the respiratory tract: (1) the mucoid character of the bronchial secretions tends to prevent implantation of cells, (2) the normal bacterial flora of the respiratory tract destroys malignant cells, and (3) respiratory motion and ciliary activity of the respiratory epithelium prevent effective implantation of foreign particles.

Mayock *et al.*[20] have demonstrated that cavitation can be simulated by lesions filled with solid or liquid caseous material and suggest that this results from a physiochemical change which increases the lipoid concentration of the contents. Curran and MacCarthy[3] cite this as a possible explanation for the apparent cavitation of pulmonary metastases from an adenocarcinoma of the rectum. In their case, expectoration was not a prominent feature and no communication of the multiple cavities with the bronchi could be shown. However, the presence of air-fluid levels in several of the cavities illustrated affords at least *prima facie* evidence of communication with the airway. Although this hypothesis might explain the apparent excavation of some of the lesions in our series, the frequent presence of air-fluid levels has been accepted by us as a reliable indication of continuity with the respiratory passageways.

Simon[33] has noted in his recent text that small and thin-walled cavities ("ring-shadows") may be neoplastic in nature. Since there is often no history of copious expectoration, he regards it as unlikely that the central air space has resulted from expulsion of the necrotic material. He suggests that in its early stages a growth may obstruct a relatively small bronchus and cause cystic distention of the air sacs distal to the block; subsequently, the neoplasm grows into the cyst forming a secondary lining of tumor cells.

Anderson and Pierce[1] postulate a similar mechanism for the occasional primary squamous cell carcinoma of the bronchus which resembles a thin-walled cyst. Examination of their operative and necropsy specimens in 6 cases revealed the linings of the cavities to be smooth and shining in some areas and rough and opaque in others. The cavity walls were composed of a mixture of fibrous tissue and well-differentiated squamous carcinoma cells. The inner surface of the cavities consisted either of these cells or of flattened squamous metaplastic

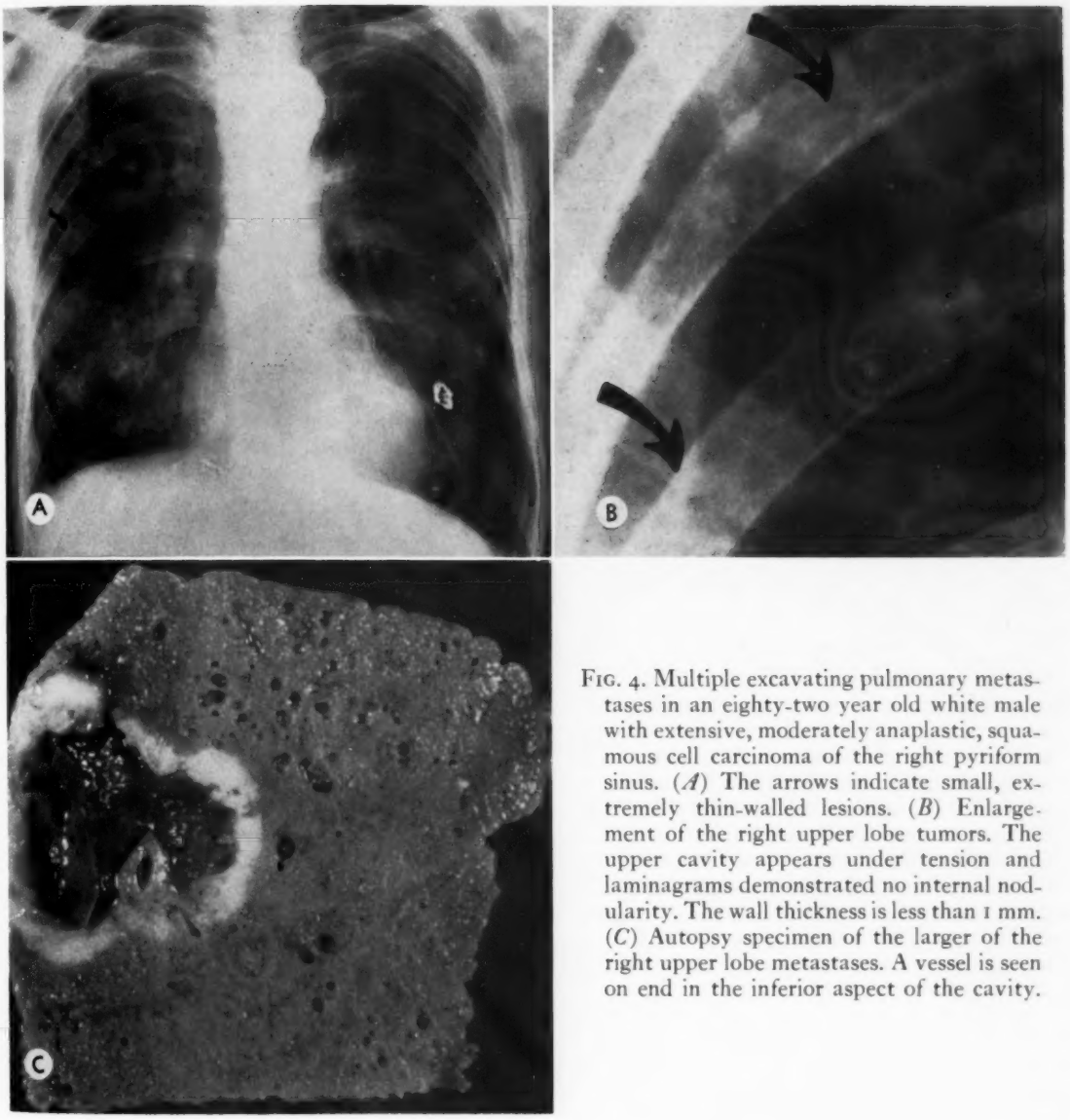

Fig. 4. Multiple excavating pulmonary metastases in an eighty-two year old white male with extensive, moderately anaplastic, squamous cell carcinoma of the right pyriform sinus. (*A*) The arrows indicate small, extremely thin-walled lesions. (*B*) Enlargement of the right upper lobe tumors. The upper cavity appears under tension and laminagrams demonstrated no internal nodularity. The wall thickness is less than 1 mm. (*C*) Autopsy specimen of the larger of the right upper lobe metastases. A vessel is seen on end in the inferior aspect of the cavity.

epithelium with malignant tissue spreading just beneath the surface. The layers of malignant cells were frequently thin and portions of the walls were formed by compressed lung only. Occasionally, a thin covering of inflammatory material was present. In no instance was degeneration or necrosis of the malignant cells noted. In view of the marked variance between these findings and the gross and histologic appearance of the usual excavating pulmonary tumor, these authors suggest that this form occurs when a thin layer of malignant cells grows into a pre-existing cavity. Such cavities may be formed by a ball-valve obstruction of a bronchus or by inflammatory changes in proximity to, but not involving, the tumor. Although unable to demonstrate positive evidence of a ball-valve obstruction in their cases, they regard the presence of a lining membrane of nonmalignant epithelium as conclusive proof of their hypothesis.

The gross and histologic findings in many of the excavating squamous cell metastases in this series were similar to those de-

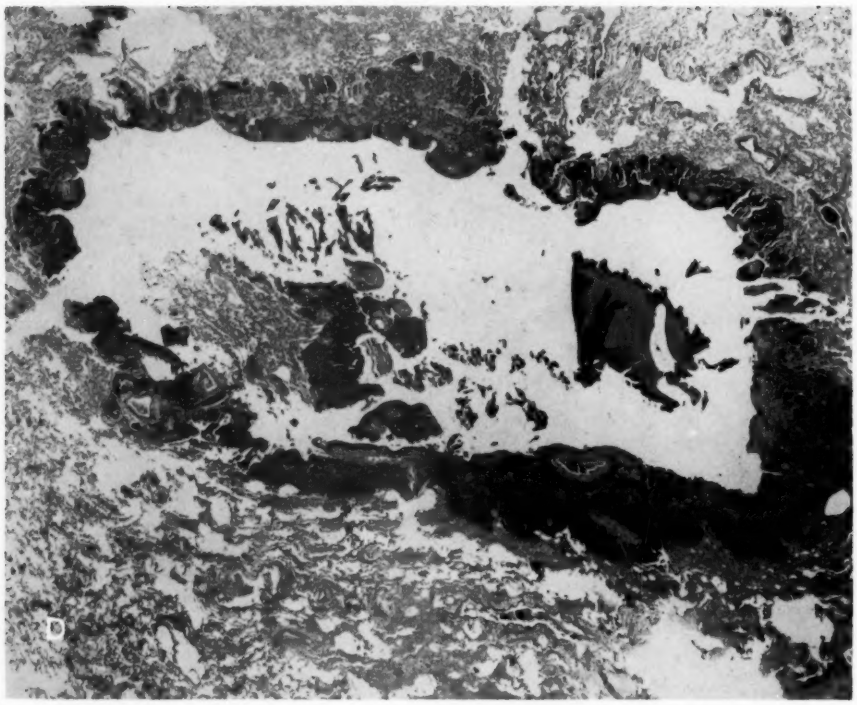

FIG. 4. (*D*) Tissue section through Figure 4*C*. The contents are artifacts. The walls are composed of malignant squamous epithelium with little evidence of degeneration. Although no definite connection with airway was demonstrable on serial sections of entire cavity, it is believed that cornified central layers have desquamated or been stripped away by respiratory motion and evacuated.

scribed by Anderson and Pierce (Fig. 4, *C* and *D*; 5, *A* and *B*; and 6 *C*). As noted by Seaman and Arneson,[30] it is often impossible to differentiate between squamous cell metastatic deposits and primary squamous cell bronchogenic carcinoma on histologic grounds alone (Fig. 1, *A* and *B*). It is also of interest that cystic metastatic deposits derived from adenocarcinoma of the colon are roentgenographically indistinguishable from the squamous cell variety (Fig. 8, *A* and *B*). Nevertheless, it does not seem reasonable to us to assume that multiple metastatic deposits would, either fortuitously or selectively, invade multiple pre-existing cavities.

The frequency of cases of excavating squamous cell tumors reported in the literature and in this series suggests that inherent properties of the normal primary tissue are a potentiating factor in the development of cavitation. In any stratified epithelial membrane which is exposed to air, the surface cells dehydrate and fuse to form a protective layer of keratin. As the deeper cells reproduce, new cells are constantly pushed toward the surface where they in turn are converted into keratin to replace desquamated layers. The same process often occurs in the center of squamous neoplastic masses but, in the absence of air, the end-product is semiliquid as contrasted to the horny character of surface keratin (Fig. 5*A*). In general, since metastases of most tumors closely reflect the structural features of the primary lesion, the degree of cornification in the metastases will parallel that of the primary tumor. This process is most evident in squamous tumors of the head and neck and, to a lesser extent, in those of the cervix and bladder. Various authors[12,30,35] have commented upon the cystic tendencies of squamous cell metastases in the lymph nodes and abdominal viscera, particularly from these locations. It is therefore not surprising that similar

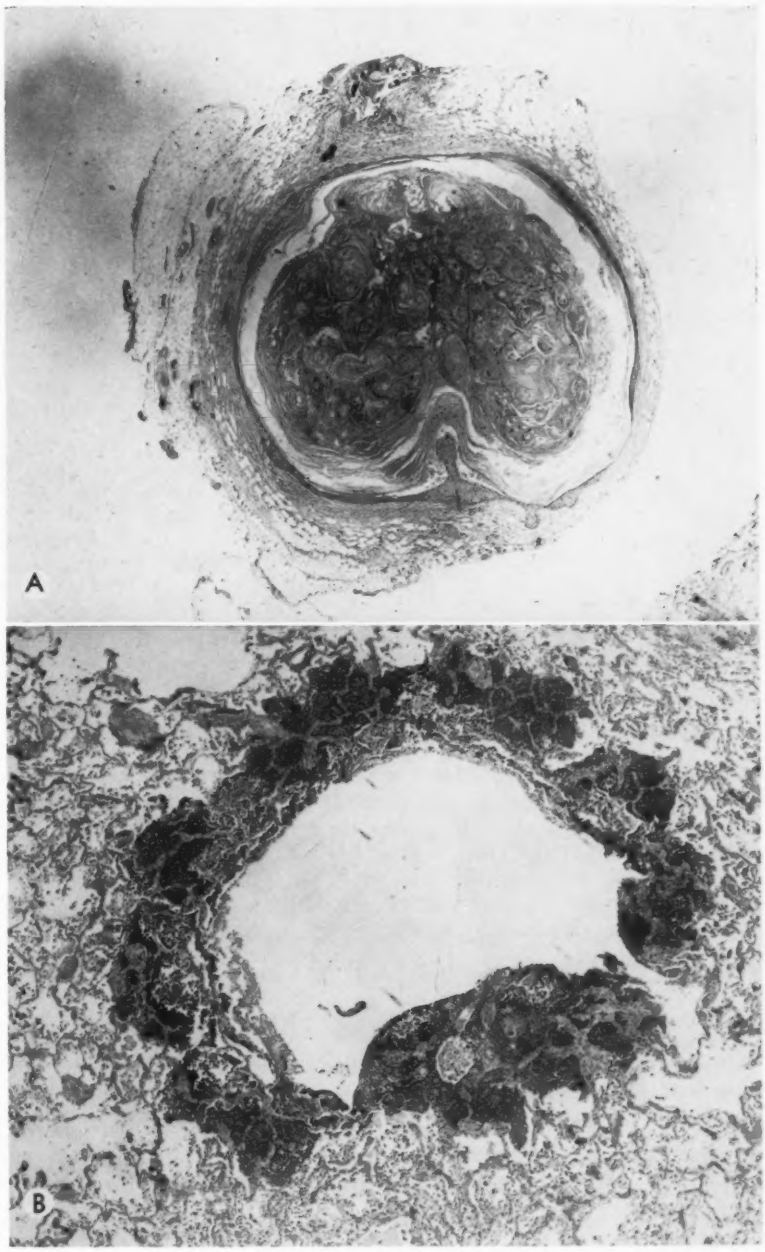

FIG. 5. Central cornification of malignant squamous epithelial masses. (*A*) Tumor-invaded lymph node from a patient with squamous cell carcinoma of the lip. Little normal architecture remains. An extremely thin layer of viable malignant squamous epithelium lines the capsule of the node; the contents largely consist of multiple layers of cornified epithelium, epithelial pearls and cellular debris. Such nodes are cyst-like on palpation, the cornified material being semiliquid in the absence of air. (*B*) A 2 mm. metastatic pulmonary nodule from the same patient illustrated in Figure 4. This was not detected roentgenographically. Note the extensive central excavation with lack of debris and little evidence of degeneration of neoplastic cells. There is probably a connection with an alveolar duct; a thin layer of tumor cells lines the duct walls. It is thought that such communications with the lesser respiratory passages permit early evacuation of the semiliquid products of cornification, leaving only the thin rim of viable tumor cells.

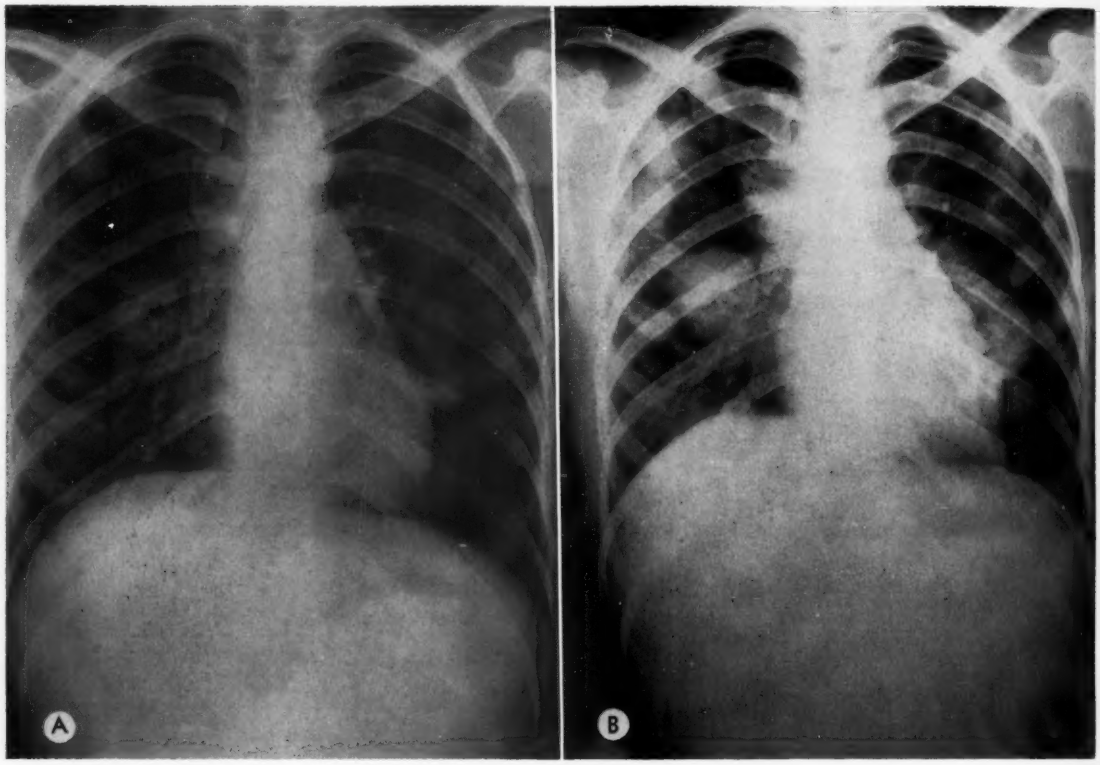

FIG. 6. Multiple excavating pulmonary metastases in a twenty-six year old white female with disseminated medullary carcinoma of breast. (*A* and *B*) Cavitation of the type described by Wigh and Gilmore.[37] In the forty-four day interval between roentgenograms, the metastases have increased in size, but the cavities have disappeared or are partially filled, presumably as the result of bronchial obstruction.

metastatic forms occur in the lungs. As a rule, in our group of cases, metastases from the head, neck and skin showed earlier and more extensive excavation than those from the cervix and bladder.

The fact that a squamous metastatic deposit may have a semiliquid center does not in itself explain the relative frequency of roentgenologically demonstrable cavitation. In the usual course of events,[38] following occlusion of an arteriole by a viable thrombus of tumor cells, the vessel wall is invaded and access to the perivascular spaces is gained. The tumor may then spread interstitially or intra-alveolarly. The latter is a frequent method of extension, the tumor employing the alveolar spongework as a stroma and extending progressively via the antra or Kohn's pores. The neoplastic tissue is avascular, the blood supply being derived from the alveolar septa. Eventually the lung architecture is destroyed in the substance of large tumors and central avascular necrosis ensues (Fig. 6 *C*). Ellis *et al.*[6] have shown that, although metastatic disease commonly involves the bronchi, the overlying bronchial mucosa usually remains intact. These authors cite this finding as an explanation for the low incidence of positive cytologic studies in metastatic disease. Since the majority of metastatic tumors undergo central degeneration only when the tumor exceeds the available blood supply, the low incidence of roentgenologically demonstrable cavitation may be similarly explained.

It is our belief that a clue to the preponderance of squamous cell lesions may be found in the extremely small metastatic deposits which have undergone extensive central excavation (Fig. 2–5, inclusive). The size of these metastases makes it highly

Fig. 6 (*C*) Tissue section of pulmonary metastasis. Note the central debris and gradual transition from viable tumor to necrotic material in contrast to the sections through the thin-walled cavities of squamous origin.

improbable that inadequate circulation is responsible for the central degeneration. However, central cornification, as an inherent characteristic of squamous epithelium, may begin almost immediately. As the tumor breaks into the alveoli, multiple opportunities for communication between the semiliquid contents and the respiratory passageways below the bronchial level occur (Fig. 5, *A* and *B*); the alveoli and alveolar ducts may be considered analogous to the "pre-formed cavities" suggested by Anderson and Pierce[1] and by Simon[33]. Once the central layers of epithelium are in contact with air, the process of cornification is further facilitated and respiratory motion assists in stripping the dehydrated, stratified material from the cavity walls. Growth meanwhile progresses peripherally, the two processes combining to increase the size of the cavity while maintaining a wall of relatively constant thickness (Fig. 7, *A* and *B*).

Adenocarcinomas may show a cystic tendency throughout the life of a tumor, presumably due to the transmission of secretory function to the metastatic deposits. Large quantities of mucin and pseudomucin may be produced, particularly by tumors primary in the gastrointestinal tract, ovary and breast. However, true mucin-secreting carcinomas occur in but 10–15 per cent of cases, mucoid degeneration of primary and secondary adenocarcinomas being more commonplace. The relationship, if any, of these processes to the excavating forms of pulmonary metastases is not clear. Both cystic and thick-walled cavities occur, the former most notably with carcinomas of the colon. Only one mucin-producing carcinoma was encountered in this series and the case illustrated in Figure 8, *A* and *B* was a well-formed adenocarcinoma in which mucin production or degeneration was not a prominent feature. Willis' contention that the pulmonary metastases of well-differentiated adenocarcinomas—particularly the mucoid variety—tend to spread via the septal pores and palisade directly upon the

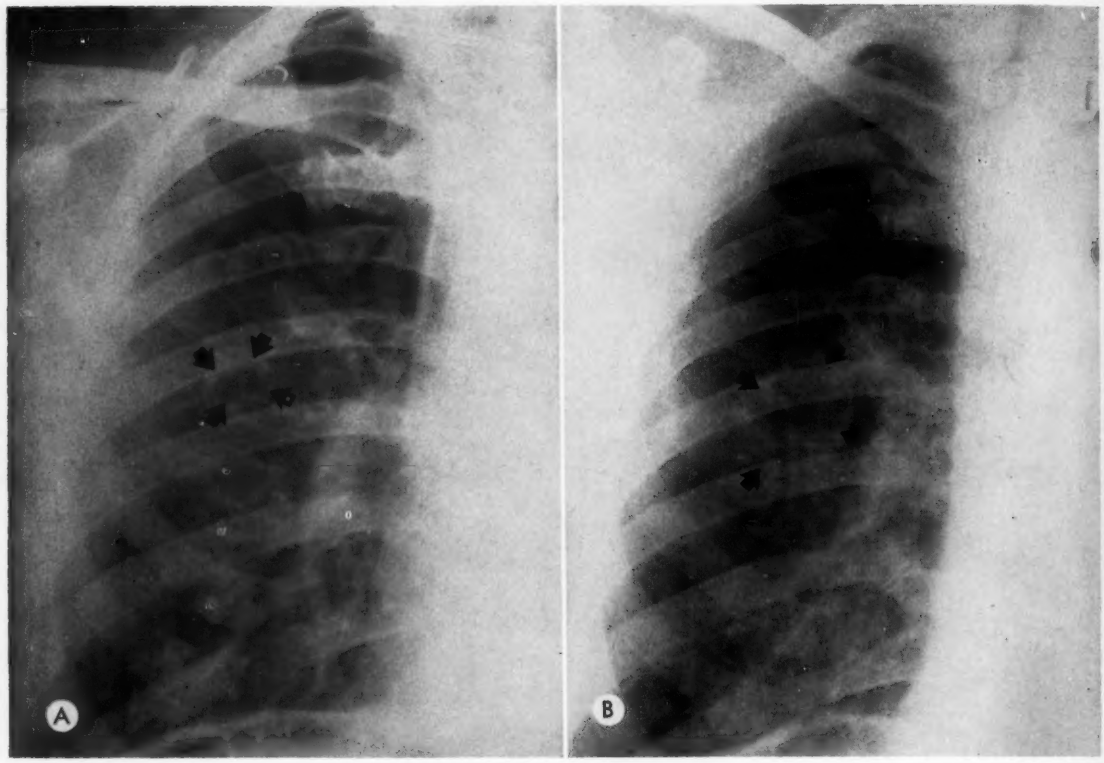

FIG. 7. (*A* and *B*) A sixty-nine year old white male with Grade III squamous cell carcinoma of the buccal mucosa. Microscopically, keratinization and pearl formation were prominent. In a two month interval between *A* and *B* the excavating metastases have increased in size, but the wall thickness remains approximately the same (2–3 mm.).

alveolar walls may be of significance.[38] But this description is disputed by some pathologists who feel that palisading is indicative of alveolar cell carcinoma, a form of tumor in which cavitation is seldom seen. Unfortunately, the tissue specimens available to us are insufficient to establish a relationship between any of these factors and excavation. Nevertheless, it seems evident that the existence of the cystic forms implies the presence of a factor or factors other than a locally inadequate blood supply.

In any form of thin-walled pulmonary cavity, an alternately smooth and crenated appearance of the external wall suggests the presence of an intermittent ball-valve bronchial obstruction (Fig. 4, *A* and *B*; 7, *A* and *B*; and 8, *A* and *B*). It is probable that such a mechanism assists in the growth of cystic neoplastic cavities. Rupture of the thin layer of tumor cells and adjacent devitalized alveoli by increases in intracavitary pressure may explain the interspaced areas of nonmalignant living tissue noted by Anderson and Pierce[1] as well as contribute to the size of the cavity.

Failure of uniform behavior by all metastases of a given tumor or group of tumors is attributable to variations in the individual neoplasms as well as to departures from parenteral structural type by the metastases. For example, not all excavating pulmonary metastases in this series from the head and neck were of the "ring" or cystic type. The same is true of the adenocarcinoma group. Presumably, those metastases which show the more typical appearance of excavating pulmonary neoplasms depend upon chance destruction of the bronchial cartilage and mucosa for expulsion of their contents; *i.e.*, the factors

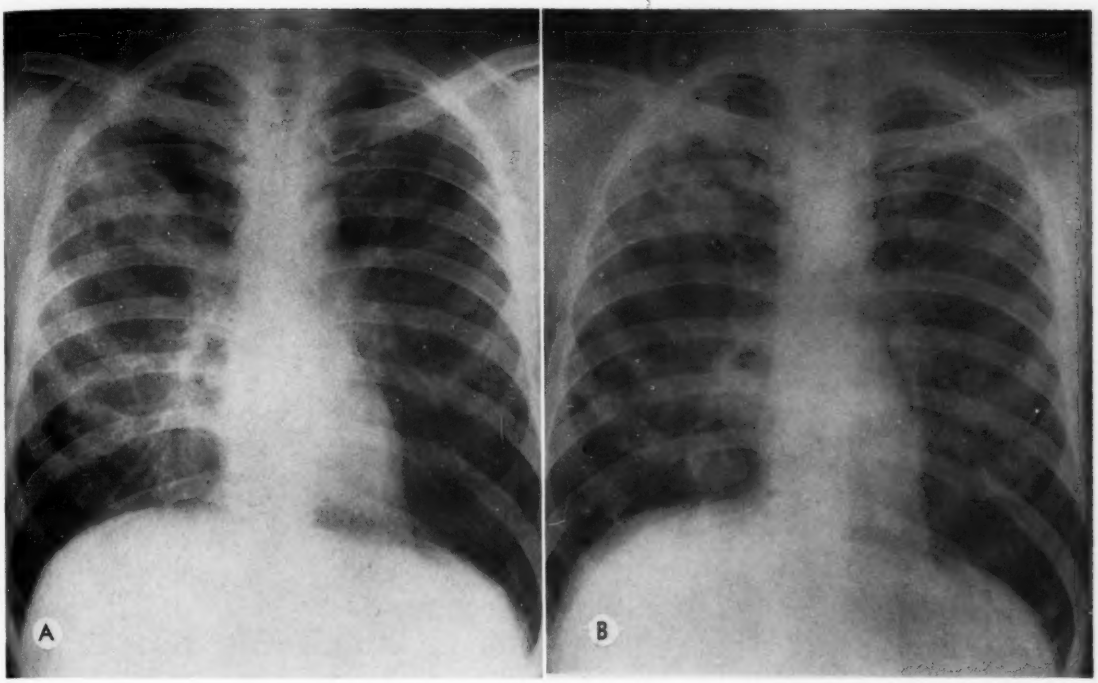

Fig. 8. Multiple excavating pulmonary metastases in a forty-six year old white male. Thirty months previously an abdominal-perineal resection had been performed for a well differentiated, nonmucoid adenocarcinoma of the rectum. The pulmonary biopsy of the right upper lobe lesion revealed a well differentiated adenocarcinoma. (Courtesy of Dr. Marjorie Le May, Boston, Massachusetts.) (*A*) Diffuse inflammatory disease involving cystic metastases of the right upper lobe. Temperature 103° F. The pneumonic process was not present on a roentgenogram made four days previously. (*B*) Seven-month follow-up roentgenogram. The metastases have increased in size and number, but the cavity walls maintain average thickness. Inflammatory disease has partially obliterated right upper lobe cavities. The large right lower lobe cavity is more irregular, suggesting the presence of intermittent ball-valve mechanism.

permissive of communication with the airway below the bronchial level are not sufficiently pronounced to allow formation of a cystic cavity. However, the relative frequency of thick-walled squamous and adenocarcinomatous metastatic cavities as compared to other cell types would indicate that these characteristics, though less effective, facilitate excavation (Fig. 9, *A* and *B*).

Cavitation in other forms of metastatic tumor is, in the majority, the result of inadequate blood supply. It should be borne in mind, however, that reported instances of necrosis in teratomas may well result from breakdown of epithelial elements. Necrosing "seminomas" may be included in this category since a biopsy of one site may be indicative of seminoma, but in other areas may contain teratomatous elements (Willis[38]).

Pancreatic neoplasms may produce metastases which retain the capacity to secrete the proteolytic and lipolytic enzymes. The functioning metastases in effect digest both their own substance and the surrounding normal tissue. None of these have been encountered in this series, but such instances are recorded in the literature.

Roentgenographic Considerations

Cavitating metastases may be single or multiple and vary greatly in size. Relatively massive lesions may be present without apparent excavation, whereas smaller deposits may, in the same patient, show central degeneration. The smallest metastatic cavity detected in this series was 8 mm.

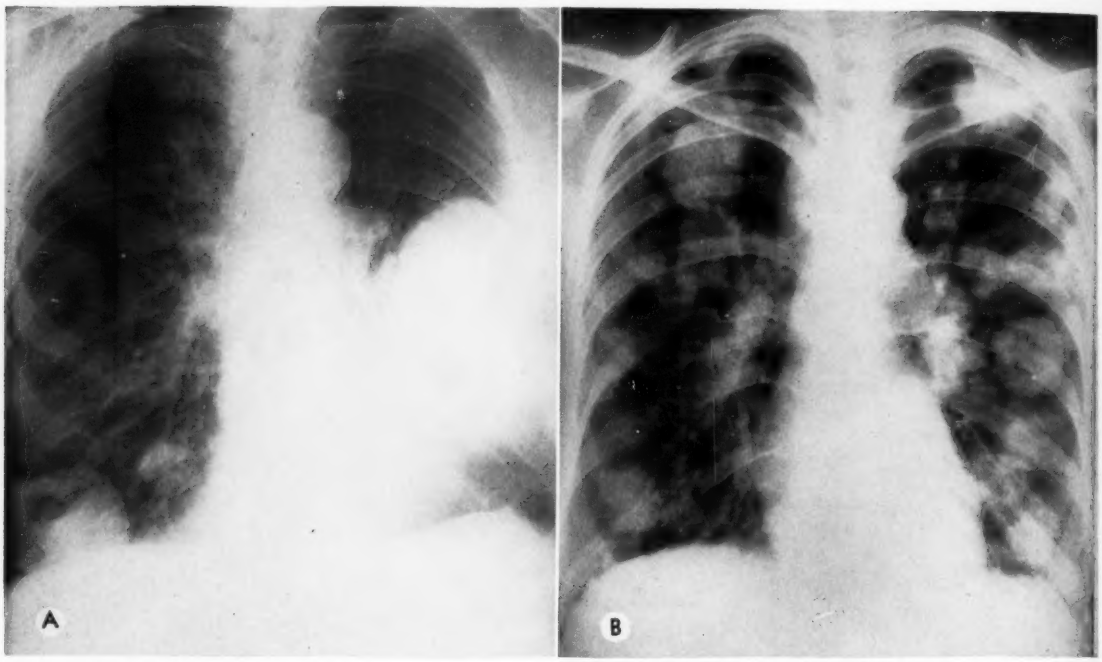

FIG. 9. Noncystic excavating pulmonary squamous cell carcinoma metastases. (A) Seventy-one year old white male. Primary lesion, Grade II papillary transitional cell carcinoma of the urinary bladder. Excavation was demonstrable only in the smaller mass. (*B*) Thirty year old white female. Primary lesion, Grade III squamous cell carcinoma of the cervix.

in diameter. If it is correct that tissue characteristics are responsible for cavitation, then it would seem logical to infer that similar changes are also present in at least some of the apparently intact nodules. The solid appearance may stem from lack of communication with a bronchus, intermittent bronchial obstruction or variations in the transmitted structural details of the metastases. Cases of unequivocal cavitation in a nodule have been observed in this series with the same lesion appearing as a solid mass on subsequent studies (Fig. 6, *A* and *B*). Evacuation of other nodules may occur during the same interval. Fluid levels are frequently seen, particularly in the larger metastases (Fig. 3, *A* and *B*; 8, *A* and *B*; and 9*A*).

The shape of thin-walled metastatic deposits may be quite bizarre, the appearance suggesting multilocular cystic disease rather than tumor. Occasionally, these will assume a more typically spherical contour, probably as the result of intermittent bronchial obstruction. Despite progressive increase in the size of the cavity, the walls are prone to maintain an average thickness, a finding which supports the theory that the older cells are shed internally.* In some instances intermittent bronchial obstruction may also be a factor in maintaining the average wall thickness (Fig. 7, *A* and *B*; and 8, *A* and *B*).

Although as a rule the criteria of Wigh and Gilmore[37] serve as reliable diagnostic signs, the nodularity of the inner wall may not always be apparent on plain roentgenograms of thin-walled lesions. Usually, this can be demonstrated by laminagraphy (Fig. 2*B*). Less commonly, the inner wall is smooth and the correct diagnosis becomes dependent upon the demonstration of solid

* The absence of significant quantities of sputum clinically does not rule out communication with the airway. The process begins early and progresses slowly with the size of the cavity dependent upon respiratory dynamics as well as tumor growth. Unless substantial bronchial obstruction occurs, only minute quantities of debris are expelled.

or cystic deposits elsewhere (Fig. 4, *A* and *B*).

Although relatively nonspecific, the identification of excavating pulmonary metastases does permit some generalization concerning their origin. Approximately 70 per cent of these will be of squamous cell origin. In the male, the bulk arise from tumors of the head and neck; in the female from the genitalia. The number of adenocarcinomas has been small, but there is no significant sex preference in the cases seen and the pulmonary forms are indistinguishable from the squamous variety. In general, the metastases originating in the head and neck undergo cavitation when quite small and have extremely thin walls. The excavating lesions of the bladder and genitalia on the whole have thicker walls and resemble the more common form of excavating pulmonary neoplasm (Fig. 9, *A* and *B*).

Spontaneous pneumothorax occurring with metastatic pulmonary cancer has been reported by several authors.[14,18,32] With the exception of one case of metastatic adenocarcinoma reported by Sherman and Brant,[32] all of these have been metastasizing sarcoma. In several instances there has been cavitation of the metastatic deposits, but the majority show spontaneous pneumothorax without obvious cavity formation. None of our cases demonstrated pneumothorax despite some instances of extensive cavitation, and pleural effusions were not common.

DIFFERENTIAL DIAGNOSIS

There are several entities which may be confused with excavating metastatic deposits in the lungs. The difficulty of differentiating between a bronchogenic carcinoma and a solitary necrosing metastatic deposit has already been discussed. Felson[8] has referred to a case of an apical cavity which was initially 8 mm. in diameter with a wall 2 mm. in thickness. This was observed over a period of approximately two years and in no instance did the wall thickness exceed 3–4 mm. even though the diameter of the cavity steadily increased. In the absence of disease elsewhere, this was felt to represent a primary bronchogenic carcinoma. At least 4 cases of bronchogenic carcinoma with excavating pulmonary metastases have been encountered in this institution subsequent to analysis of this series.

Smaller pulmonary cysts may be confused with thin-walled cavitating nodules, especially when repeated bouts of inflammatory disease in the cysts have distorted the margins. Peabody *et al.*[24,25] have reported an example of bronchial carcinoma arising in a lung cyst.

Multiple pulmonary abscesses, particularly those which occur with staphylococcic pyemias or showers of small septic emboli may produce well defined densities highly suggestive of nodular metastases. With the development of central destruction, cavitation with fluid levels may be evident.[28]

In the granulomatous group of lesions, the cavities found in aspergillosis, coccidiomycosis and chronic tuberculosis represent the more important differential entities.

Less commonly, varicella pneumonia may appear as well circumscribed nodular deposits in the lung fields which subsequently excavate, the roentgen appearance being indistinguishable from that of excavating metastases.[16] Forsee and Blake[9] have reported 4 patients with systemic xanthomatoses in which sharply defined pulmonary nodules and concomitant cyst-like changes in the lung were demonstrable. These resulted from obstruction of bronchi by submucosal infiltration of xanthoma cells.

SUMMARY AND CONCLUSIONS

1. Sixteen new cases of excavating pulmonary metastases are presented.

2. In a series of 6,729 consecutive patients seen in a tumor institution, excavation was encountered in 9 per cent of patients with primary tumors of the lung and 4 per cent of patients with pulmonary metastases.

3. Sixty-nine per cent of the excavating metastases were of squamous cell origin as

were all of the bronchogenic carcinomas. Thirty-one per cent were derived from adenocarcinomas of breast and colon. This distribution was paralleled in a control series of patients (12 cases).

4. The possible mechanisms of excavation are discussed. It has been concluded that specific tissue characteristics are primarily responsible for the majority of roentgenographically detectable excavating metastases rather than deficiency in the blood supply *per se*.

5. The roentgen criteria and differential diagnosis of excavating pulmonary neoplasms are enumerated and the feasibility of identifying the primary tumor from the characteristics of its metastases is considered.

Gerald D. Dodd, M.D.
The University of Texas
M.D. Anderson Hospital and Tumor Institute
The Texas Medical Center
Houston, Texas

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PRIMARY LYMPHOSARCOMA OF THE LUNG*

By MURRAY G. BARON, M.D.,† *and* WALTER M. WHITEHOUSE, M.D.
ANN ARBOR, MICHIGAN

LYMPHOSARCOMA may occasionally arise primarily in the pulmonary parenchyma without involvement of lymph nodes or other organs until late in the course of the disease. This localized form of the disease is an entity clinically separate from generalized lymphosarcoma. It is not certain if it is a malignant process from its inception or if it represents malignant degeneration of a so-called "benign lymphoma." The tumor is relatively slow growing and remains limited to the lung for variable periods of time. Because of this, treatment in the form of excision or irradiation should be designed to be curative rather than palliative as the prognosis, in those cases which have not metastasized, is good.

Since it involves only the lung, lymph node biopsy, marrow studies and other procedures used in the study of generalized lymphosarcoma are of no value in the diagnosis of primary pulmonary lymphosarcoma. The problem resolves itself into one of a mass in the lung of unknown etiology. Although the ultimate diagnosis in most cases will have to be made at the time of thoracotomy, certain clinical and roentgenographic features can suggest the diagnosis preoperatively.

Primary lymphosarcoma in the lung is quite rare. Robbins,[23] in a review of 715 cases of all types of lymphoma of which 7 per cent showed roentgen evidence of pulmonary involvement, found none which could be considered primary in the lung. Only 1 of the 196 cases of lymphosarcoma reported by Sugarbaker and Craver[32] was felt to arise in the lung and none of the 220 cases of lymphosarcoma in the series of Gall and Mallory.[10] Thus, a primary localization of lymphosarcoma in the lung is less common than it is, for example, in the stomach, tonsils or nasopharynx.

We have found 34 documented cases of primary pulmonary lymphosarcoma in the literature. A review of these cases together with 5 to be reported constitute the material for this report. Our cases were drawn from the Surgical Pathology files of The University of Michigan Medical Center and have all been proved by study of the specimen removed or biopsied at the time of thoracotomy.

REPORT OF CASES

CASE 1. J.J., No. 632–681, a thirty-seven year old white female, was well until February, 1946, when she developed right sided pneumonia and pleurisy. This responded to treatment but she continued to have pain in the right lower thorax on deep inspiration. A year and a half later, following an upper respiratory infection, she felt weak and tired and began to cough, producing small amounts of grayish, odorless sputum. Her local physician noted clubbing of the fingers at this time. Cough and pleuritic pain continued until her admission to University Hospital on March 7, 1948. There was a ten pound weight loss over the previous year.

Positive physical findings were limited to the chest and the clubbing of the fingers. Routine laboratory studies were within normal limits. A roentgenogram of the chest (Fig. 1) revealed a homogeneous consolidation of the right lower lung. A bronchogram (Fig. 2) showed incomplete filling of the right lower lobe branches. The distal bronchi were tapered and some appeared to be compressed and displaced by the mass. At the time of bronchoscopy, the mucosa of the right lower lobe bronchus was found to be edematous and hyperemic. The basilar divisions were patent, although there was some narrowing of the posterior and mesial basal segments.

On April 21, 1948, thoracotomy was per-

* From the Department of Radiology, The University of Michigan Medical Center, Ann Arbor, Michigan.
† Present address: Department of Radiology, The Mount Sinai Hospital, New York, New York.

formed. The right lower lobe was found to be adherent to the chest wall. When this lobe was palpated through the long fissure, small nodules could be felt throughout its substance. The lung was fixed to the diaphragm. Exploration of the hilus showed tumor extending into the mediastinum. The tumor was biopsied and the chest closed. The microscopic diagnosis was lymphoblastoma infiltrating the lung.

Irradiation of the right lung and mediastinum was accomplished through anterior, posterior and right chest fields, using 200 kv., half value layer 1.0 mm. copper, focus skin distance 50 cm. A dose of 1,225 r in air was delivered to each field in a total of nineteen days. The patient has done well since her irradiation although she notices occasional blood streaking of her sputum. She underwent a subtotal gastrectomy for ulcer in 1951 without incident and was last heard from on February 17, 1958 at which time she was in good health.

Case II. F.M., No. 703-049, a sixty-four year old white male, was first seen at University Hospital on April 18, 1951 because of a bursitis of the left shoulder. A minifilm of the chest at this time showed a lesion in the left upper lung that was interpreted as localized pleural thickening. The patient was seen again in September, 1952 at which time he was asymptomatic. A chest roentgenogram (Fig. 3) once more showed the left upper lobe abnormality which had not changed over the past eighteen months. Bronchograms at this time were completely negative, the left upper lobe bronchi being of normal caliber and pursuing a normal course. Because of these findings it was felt that this lesion was not neoplastic and it was elected to continue observation of the patient. No change was noted during his examination in October, 1953 and the patient was not seen again until 1956 when comparison of a mobile survey chest roentgenogram made at that time with our previous roentgenograms showed some increase in the size of his pulmonary lesion.

He was admitted to University Hospital on September 27, 1956. Physical examination was negative except for a 2 cm. lymph node in the left axilla. Tuberculin skin test was positive; all other skin tests were negative. Routine laboratory studies were within normal limits. Roentgenograms of the chest, September 27,

Fig. 2. Case I. Bronchogram showing incomplete filling of the right lower lobe, with tapering of branches, compression and displacement.

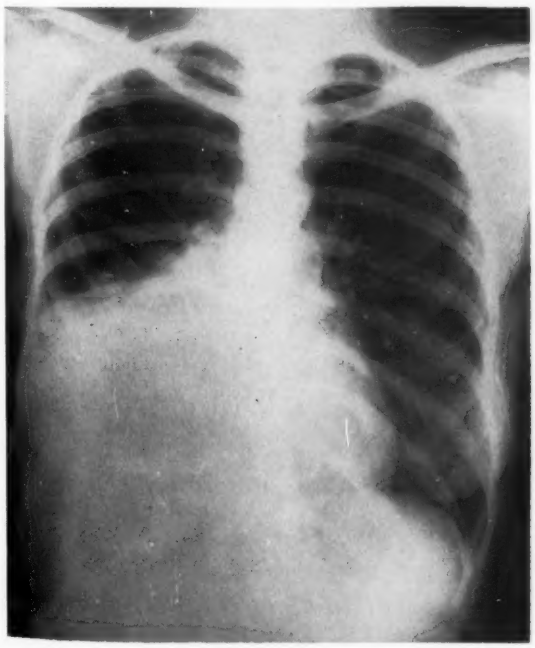

Fig. 1. Case I. Homogeneous consolidation in right lower lung.

FIG. 3. Case II. Left upper lobe abnormality which did not show any change in eighteen months.

1956, showed a mass in the left upper lobe with a finely irregular margin. Air filled bronchi were visible within the mass (Fig. 4). A bronchogram showed a normal bronchial tree (Fig. 5). A laminagram of the left upper lobe demonstrated the patent bronchi within the mass (Fig. 6). Bronchoscopy was negative and bronchial washings were negative for malignant cells and acid fast bacilli. Excisional biopsy of the left axillary lymph node showed chronic hyperplastic lymphadenitis and no neoplasm.

Thoractomy was performed on December 7, 1956. A moderately firm mass was palpated in the anterior and apical posterior segments of the left upper lobe. It appeared to be adherent to the chest wall and mediastinum. The tumor was dissected away and biopsy of the remaining mediastinum showed no neoplasm. Mediastinal and hilar lymph nodes were not felt to be involved. Microscopic examination revealed a lymphoblastoma of lymphosarcoma type. One lymph node in the hilus showed changes suggestive of early lymphoblastomatous involvement, but the remainder of the lymph nodes were negative.

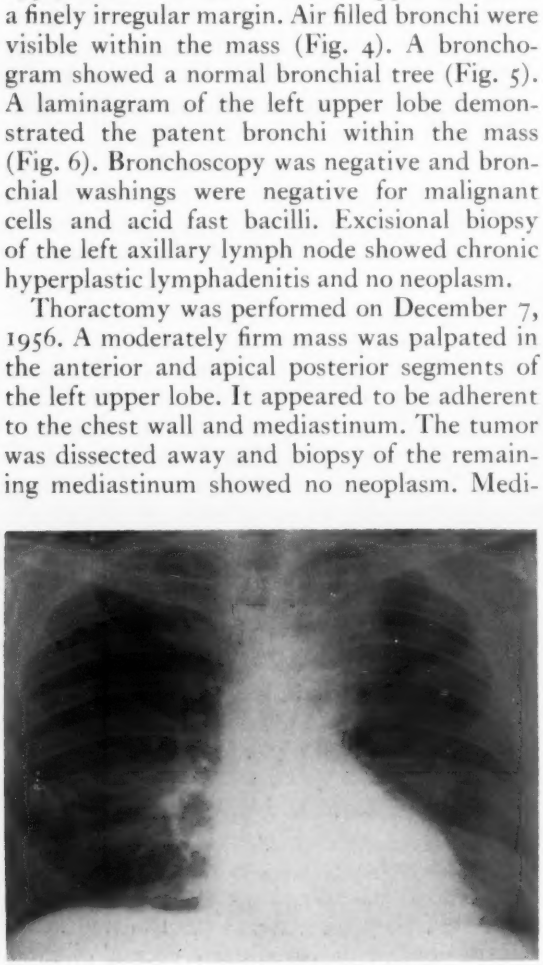

FIG. 4. Case II. Increasing mass in left upper lobe.

FIG. 5. Case II. No bronchographic abnormality is visualized in the region of the mass.

FIG. 6. Case II. Laminagram confirming patent bronchi within the mass.

The patient's postoperative course was uneventful. No radiation therapy was given. At the time of an annual examination, May 13, 1959, he was found to be in excellent condition with no evidence of recurrence of his disease.

Case III. E.V., No. 849-076, a forty-nine year old female, was admitted to University Hospital on August 12, 1956. Eight months prior to this a "spot" on the right lung was noted on a minifilm of the chest during a routine survey. The patient was completely asymptomatic.

Physical examination and routine laboratory studies were negative. All skin tests were negative. Atypical acid fast bacilli were cultured from the sputum. A roentgenogram of the chest (Fig. 7) showed a mass in the hilar portion of the right middle lobe. The margins were poorly demarcated. The hilus was not enlarged and the vessels at the hilus appeared to be normal. The appearance of the chest was identical with that on roentgenograms made elsewhere on January 10, 1956. Bronchoscopy revealed no abnormality except for some slight narrowing of the branches to the right lower lung. Bronchograms were normal. Filling of both segments of the middle lobe was obtained (Fig. 8). Bronchial washings were negative for malignant cells.

On August 21, 1956 a right middle and upper lobectomy was performed. There was fleshy consolidation of the middle lobe and the disease crossed the horizontal fissure to involve the upper lobe. Hilar and mediastinal lymph nodes were not involved. Microscopic examination showed widespread infiltration of both lobes by lymphosarcoma. This was especially heavy around the lesser bronchi. All lymph nodes were negative.

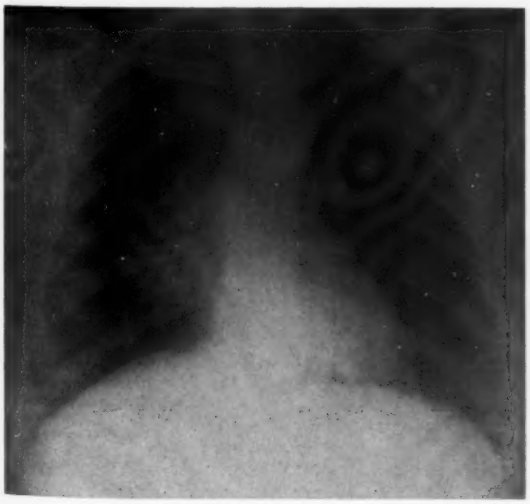

Fig. 7. Case III. Right middle lobe hilar mass which was first seen on a survey roentgenogram.

Fig. 8. Case III. Patent bronchi in the area of the mass.

The patient received postoperative irradiation elsewhere and was last heard from on May 1, 1959 at which time she was well.

Case IV. N.G., No. 132-866, a fifty-six year old female, gave a history of having had pleurisy in 1937. In 1943 she had had pneumonia and pleurisy in the left lung and in 1944 pneumonia in the right lung. Since that time she had been bothered with numerous "chest colds." In November, 1955, a mobile survey roentgenogram revealed changes of bilateral apical tuberculosis. She was hospitalized, treated with INH and PAS with rapid clearing of the lesions and was discharged in August, 1956. About eight months later, she noted the onset of dyspnea on exertion and a feeling of tightness in her chest. A roentgenogram revealed a lesion in the right lung. Repeat examination one month later was reported to show an increase in the size of this lesion. She was

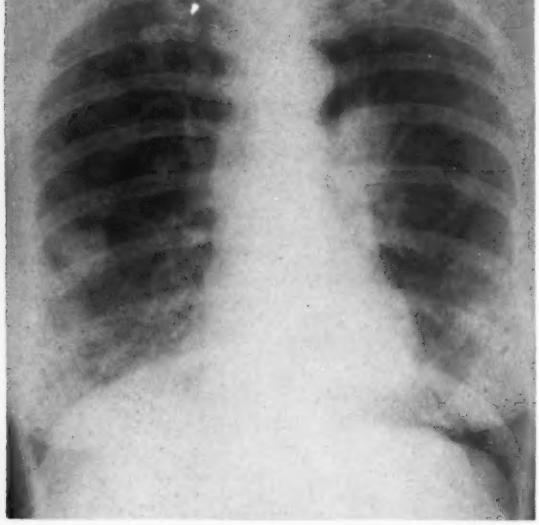

FIG. 9. Case IV. Left hilar mass and excavated nodule in right middle lobe.

admitted to University Hospital on May 19, 1957.

Positive physical findings were limited to the chest. Routine laboratory studies were negative except for a hemoglobin of 11.5 gm. A roentgenogram of the chest on May 17, 1957 (Fig. 9) revealed a mass extending into the left upper lobe from the hilus. A second mass was present in the peripheral portion of the right middle lobe. This second lesion appeared to be cavitary. Bilateral apical pleural scarring was present. On laminagrams (Fig. 10, *A* and *B*) the left upper lobe lesion could not be separated from the hilus, although it appeared to involve lung parenchyma. Enlarged lymph nodes were not identified. Air filled bronchi could be seen within the mass. A cavity was definitely present in the right lung lesion. Left scalene lymph node biopsy revealed only hyperplastic lymph nodes and no neoplasm. On May 31, 1957, the patient was bronchoscoped. Using the right angle lens, the orifice of the left upper lobe bronchus appeared to be re-

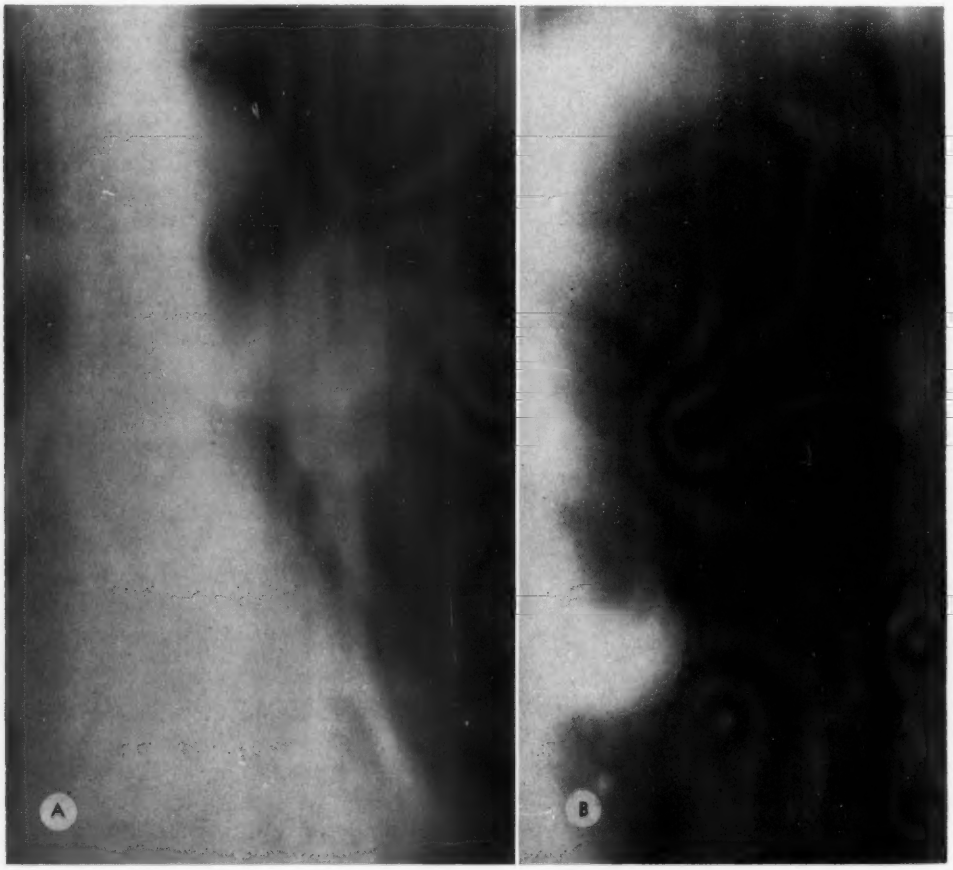

FIG. 10. Case IV. (*A*) Laminagram through the left hilar mass. (*B*) Laminagram through the right middle lobe showing excavated nodule.

duced to a slit. The mucosa appeared normal and the narrowing was thought to be due to extrinsic pressure. Biopsy of the mucosa near this bronchial orifice was reported as showing two small collections of markedly hyperchromatic cells which raised the possibility of carcinoma, although this diagnosis could not be definitely made.

Right thoracotomy was done on June 3, 1957. A rounded, somewhat soft lesion, 2.5 cm. in diameter, was found in the right middle lobe. The pleura overlying the lesion was grayish-white in color. A wedge resection was performed. Microscopic examination revealed lymphosarcoma.

The patient was given postoperative radiation therapy. Anterior and posterior right and left chest fields were used, each field measuring 14×11 cm. The factors were: 220 kv., half value layer 1.5 mm. copper and focus skin distance 50 cm. A dose of 1,625 r measured in air was delivered to each field over twenty-six days. There was a marked decrease in the size of the left hilar lesion following irradiation. Clinically, the patient was definitely improved. Three months later she began to notice some shortness of breath and substernal discomfort. Roentgenograms of the chest showed bilateral parenchymal abnormality and a second course of radiation therapy was administered, 1,200 r in air being delivered to each of the four chest fields. There was slight improvement in symptoms following this. One month later she began to vomit and her condition deteriorated appreciably.

On December 12, 1957 she was re-admitted to this hospital with severe dyspnea at rest and a temperature of 103°F. She complained of intermittent chest pain and cough productive of a thick, mucoid sputum. There was no hemoptysis and no clubbing of the fingers. A chest roentgenogram made at this time (Fig. 11) revealed an increase in the size and extent of the bilateral parenchymal infiltrations since the previous roentgenogram made two months before. She was given a course of intravenous nitrogen mustard with minimal relief from her symptoms. The patient died on January 26, 1958. An autopsy was not performed.

Case v. B.L., No. 786-529, a fifty-seven year old male, was admitted to University Hospital on June 6, 1954. In February, 1953 he "caught a cold" and noted chills and fever and ease of fatigue. It was felt that he had lobar pneumonia and pleurisy, and he was treated

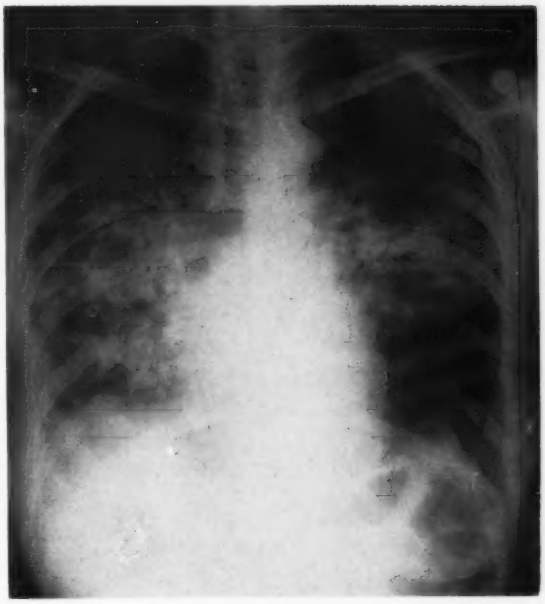

Fig. 11. Case iv. Extensive bilateral spread found five months after irradiation.

with penicillin and streptomycin with relief of his symptoms. Review of a chest roentgenogram made at that time showed a large left pleural effusion obscuring the lower left lung and displacing the mediastinum to the right. One month following treatment, he began to notice ease of fatigue and some shortness of breath. Thoracentesis was performed three times and fluid was removed at each tapping. In August, 1953, because of increase of his symptoms he was hospitalized elsewhere for six months. He was finally advised to have an operation which he refused. He went back to work but was forced to return to a hospital because of his extreme weakness.

Physical findings were limited to the lungs. Routine laboratory tests and skin tests were negative. A roentgenogram of the chest on admission (Fig. 12) showed a large, hemispherical mass with an irregular margin in the posterobasal segment of the left lower lobe. On lateral projection the posterior costophrenic sulcus was obliterated. In view of the previous roentgenograms, this was thought to represent a loculated pleural effusion. Thoracentesis was performed on the following day and 300 cc. of serosanguineous fluid was removed. Chest roentgenograms following the tapping showed no change in the appearance of the mass.

On June 28, 1954 a thoracotomy was done with the object of draining the empyema. A 6 cm. incision was made along the left tenth

FIG. 12. Case v. Large mass found at left base posteriorly.

rib posteriorly and a portion of the rib was removed. The parietal pleura in the region was 1 to 2 cm. thick and shaggy but not fibrotic. In the pleural space 300–500 cc. of turbid fluid was found. Finger palpation of the lung that fitted into the mediastinal portion of the posterior costophrenic sulcus showed it to be firm and to contain less air than the lung laterally. It was felt that this was due to the prolonged collapse of the lung. A rubber drain was placed in the costophrenic sulcus and the chest was closed. Microscopic examination of the pleural fluid revealed leukocytes, fibrin and serosal lining cells, but no malignancy. Operative biopsy of the pleura showed heavy subpleural infiltrates. There was no evidence of inflammatory reaction on the pleural surfaces. The patient did well postoperatively and was discharged, the diagnosis being sterile empyema following antibiotic therapy.

In August, 1954 a follow-up examination showed some increase in the size of the mass on chest roentgenograms. There also appeared to be some abnormality in the lingular portion of the left upper lobe. A bronchogram showed incomplete filling of the posterobasal branches with shortening and tapering of these bronchi (Fig. 13*A*). Bronchoscopy was negative. The patient's chest was tapped posteriorly and 4 cc. of straw colored fluid was obtained. An operation was advised but the patient refused.

He was well until May, 1957 when, following an upper respiratory infection, he noted some shortness of breath and a cough productive of grayish sputum which was occasionally streaked with blood. He was re-admitted to the hospital. Physical examination revealed no lymphadenopathy; the liver and spleen were not palpable. Chest roentgenograms showed considerable increase in the size of the mass and a left pleural effusion was present. On September 24, 850 cc. of fluid was removed from the left pleural space. Microscopic examination was negative for malignant cells. A left scalene fat pad biopsy showed reticuloendothelial hyperplasia of the lymph nodes but no malignancy. Bronchograms made at this time demonstrated the increase in the size of the pulmonary lesion and further shortening, tapering and displacement of the bronchi when compared with the examination three years previously. The disease process appeared to involve the peripheral bronchi initially, then proceeded towards the hilus (Fig. 13*B*).

Thoracotomy was done on October 10, 1957. On entering the thoracic space it was noted that the lower lobe was completely adherent to the parietal wall. Over the lingula anteriorly were only a few adhesions. The lower lobe was represented by a bulky mass of firm tissue and even an extrapleural plane could not be established. The mass was freed by finger dissection. A left lower lobectomy was performed. Several enlarged lymph nodes were found near the hilus. Examination of the removed lobe showed it to be filled with 1–2 cm. of tan colored, rubbery nodules which became confluent in places. One large mass, measuring 21×14 cm. was composed of this tissue, which microscopically was lymphocarcoma with extensive invasion of the peribronchial tissues and interalveolar septa. Then neoplasm extended along the major lobar bronchus and almost completely infiltrated its wall. The removed lymph nodes were all involved.

The patient had several complications arising from the surgery and required numerous thoracenteses, all of which were negative for malignant cells. He had several episodes of hemoptysis immediately after the operation. Postoperative irradiation was given through 15×12 cm. anterior and posterior left chest fields. The factors were 220 kv., half value layer 1.5 mm. Cu and a focus skin distance of 50 cm. A total of 1,875 r in air was given to each

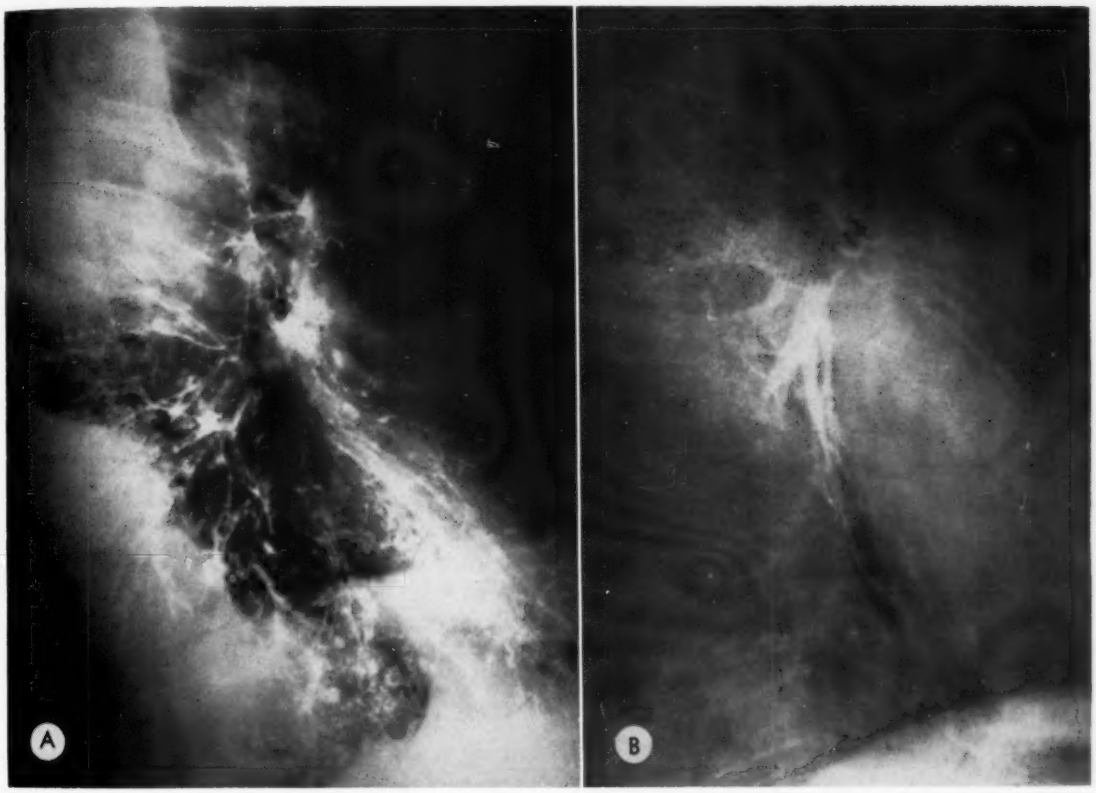

Fig. 13. Case v. (*A*) Bronchogram showing patency of bronchi in region of mass. (*B*) Increase in mass over three year period with further tapering and displacement of bronchi.

field over a period of eighteen days. The patient was last heard from in March, 1959, at which time he was well.

CLINICAL FEATURES

In 39 cases of primary pulmonary lymphosarcoma, 5 of which are reported here and 34 collected from the literature, the average age at the time of diagnosis was 51.9 years, the range being from thirty-four to seventy-five years. There were 16 males and 22 females, a ratio of about 3:4. Three of this group were Negroes, the remainder were Caucasians.

There is no definite symptom complex associated with this disease. Almost one-third of the patients were completely asymptomatic, the pulmonary lesion first being detected on survey chest roentgenograms or at the time of examination for complaints not referable to the respiratory tract. The most common symptom was cough usually productive of small amounts of mucoid sputum. This was present in 23 of 38 patients. Hemoptysis occurred in 6 cases and was in the form of pinkish or blood streaked sputum. Massive hemoptysis was not encountered. Chest pain usually localized to the side of the lesion was noted by 11 patients. This was generally of an aching nature; the pleuritic-type pain being less common. Three patients were first seen because of pain in the shoulder and in each case the lesion was in the upper lobe on the same side.

Physical examination, except for findings related to the chest, was negative. If lymphadenopathy, hepatomegaly or splenomegaly are present, the pulmonary involvement is most likely secondary to generalized lymphosarcomatosis. Two patients had clubbing of the fingers. In a case described by Cooley *et al.*,[5] the lesion had a large central cavity and pleural effusion

was present, while in our Case 1 there was a previous history of pneumonia and pleurisy. It is felt that the clubbing is not due to the lymphosarcoma *per se*, but to the accompanying infection.

A history of recurrent episodes of pneumonitis or upper respiratory tract infections was definitely more common among the patients with pulmonary lymphosarcoma than would be expected in the average population.

Routine laboratory studies are generally normal. An occasional patient may have a moderately low hemoglobin or elevated erythrocyte sedimentation rate, but these are of no diagnostic value.

PATHOLOGY

There is abundant lymphoid tissue in the normal lung. The bronchial mucosa is infiltrated with lymphocytes and may contain lymphoid follicles. Lymphoid tissue extends as far peripherally as the alveolar ducts. Accumulations of lymphocytes and lymph channels are present in the adventitia of the arteries and veins in the lung, in the pleura and interlobar connective tissue.[18] As with lymphoid tissue elsewhere in the body, these foci may undergo lymphosarcomatous change.

Lymphosarcoma in the lung is essentially an infiltrative process. The principal mode of spread of the tumor is by contiguous growth. The peribronchial lymphoid tissue is commonly involved, but the tumor tends to grow away from, rather than into, the bronchial lumen. The malignant cells may penetrate almost the entire thickness of the bronchial wall, in some cases destroying the bronchial cartilages;[11] submucosal collections of lymphosarcoma cells are commonly seen, but it is rare for the bronchial mucosa to be ulcerated. Such ulceration was found in 4 of the 39 cases and in only one of these (Hall and Blades,[12] Case 1) was there sufficient intrabronchial growth to produce obstruction. The blood vessels are affected in a like manner. In almost every case report, the patency of the bronchi and blood vessels within the tumor is commented on.

As the tumor infiltrates the interalveolar septa, the cellular accumulation produces marked thickening of these structures. Eventually, adjacent septa become so swollen that the alveolar air space between them is obliterated. It is extremely uncommon to find free lymphosarcoma cells within a recognizable alveolus. As the disease progresses, there is gradual loss of the pulmonary architecture so that in the more advanced stages the tumor appears to consist solely of lymphosarcomatous elements, the normal pulmonary tissue having been completely destroyed.

The tumor is not encapsulated although a rim of compressed normal lung may surround it. Microscopically, the borders of the tumor are not distinct because of the multiple small extensions of malignant cells into the adjacent septa. The pleura seems to offer no barrier to the growth of the lymphosarcoma, and contiguous lobes and pleural surfaces are usually involved.

Metastases probably occur late in the course of the disease and may represent hematogenous or lymphogenous spread. The most common site of secondary involvement is the hilar and mediastinal lymph nodes. Cases have been reported of metastases to the skull,[12] spine,[12] ribs,[12,21] liver,[21] lung,[4,17,30] submaxillary gland,[4] and parotid gland.[16] In our Case v it is felt that the cavitary lesion in the right lung probably represented a metastasis and the bilateral pulmonary disease leading to the patient's death was most likely spread of lymphosarcoma.

Two cases have been reported which possibly represent multiple primary sites in the same patient. In the case of Beck and Reganis,[3] two years following lobectomy for primary lymphosarcoma of the lung, gastroscopic diagnosis of lymphosarcoma of the stomach was made and a gastric resection performed. The patient was last reported well and without evidence of disease five and one-half years following lobectomy. The patient reported by Justin-Besancon *et al.*[16] originally had bilateral lymphosarcoma of the lung which was

treated by radiation therapy. She did well for five years and then developed an antral ulcer which was found to be lymphosarcomatous at the time of gastrectomy. Subsequently, she had involvement of the ileum and recurrence of the sarcoma in the lung and died eight years after the original diagnosis was made.

The microscopic pathology of primary lymphosarcoma in the lung is identical with that of generalized lymphosarcoma. In most of the cases, the tumor was composed of mature lymphocytes with few mitoses being seen. In a few of the cases, the cells appeared to be less mature and were described as lymphoblasts.

BRONCHOSCOPIC FINDINGS

Bronchoscopic findings are known in 29 cases. In 12 they were completely normal. In one case an ulcerating lesion was seen which proved to be lymphosarcoma by biopsy. In a second case, biopsy of an intact friable mucosa revealed a collection of malignant cells submucosally which were felt to represent either small cell anaplastic carcinoma or lymphosarcoma. These are the only 2 cases in which the correct diagnosis was made preoperatively. Some mucosal abnormality in the region of the bronchus from the involved lobe was found in 6 other patients. This generally was an area of granularity or edema and hyperemia. In most of these, biopsy revealed only inflammatory tissue. Nine cases showed evidence of extrinsic pressure on a bronchus without mucosal involvement.

Examination of the sputum and bronchial washings were negative in 11 of the 14 cases in which it was reported. In 3 cases, malignant cells were found, but their type could not be identified.

ROENTGEN FINDINGS

Primary lymphosarcoma of the lung appears on chest roentgenograms as a homogeneous mass, often occupying an entire lobe. There is no apparent predilection as to the lobe involved: 11 of 39 cases were in the left upper lobe, 9 in the right lower lobe, 6 in the left lower lobe, 6 in the right upper lobe and 3 in the right middle lobe. Four cases showed bilateral lung involvement at the time the diagnosis was made. In all cases the mass was sizable when first detected, the smallest lesion being 3 cm. in diameter. The tumor tends to develop in the hilar portion of the lobe rather than peripherally, probably because of the greater concentration of lymphoid tissue around the larger bronchi.

On roentgenograms the mass is usually well demarcated from normal lung, although its margins are somewhat hazy and irregular because of small extensions into the surrounding alveolar septa. As obstruction of the major bronchi almost never occurs; significant atelectasis is rarely seen. The infiltration and enlargement of the interalveolar septa with obliteration of the alveoli produce the roentgen picture of consolidation with minimal, if any, loss of lung volume. The bronchi remain patent and traverse the mass so that in some cases an air bronchogram may be seen (Fig. 5, 8, and 13*A*).

Pleural involvement was commonly noted at the time of thoracotomy in our patients, the lymphosarcoma fusing the visceral and parietal layers. Despite this, pleural effusion in these cases is rare. Such an effusion was present in one of our patients (Case v) and in 3 reported in the literature. Microscopic examination of the fluid revealed malignant cells in only one case (Sternberg *et al.*,[30] Case 6).

In only one of the reported cases has the lesion shown some suggestion of calcification within the mass (Grimes *et al.*,[11] Case 2). In 3 of the remaining 38 cases there was cavitation within the tumor. Case 3 in the series of Sternberg *et al.*[30] had a cavity measuring 7 cm. in diameter, the walls being formed by necrotic tumor tissue. A smooth-walled cavity, 8 cm. in diameter, was present in Case 5 reported by Cooley *et al.*[5] There was a smaller cavity in the right lung lesion in Case IV of our series (Fig. 10*B*). In one case, multiple small bronchiectatic cavities were found within

the mass on pathologic examination.[29] Because of the frequent respiratory infections, pneumonic changes in the lungs may obscure the underlying neoplasm, which will then become evident following treatment with antibiotics. Hilar or mediastinal lymphadenopathy was not present roentgenographically in any of the cases.

Information concerning bronchography is available in 9 cases. Three were normal and one showed incomplete filling of the bronchi of the involved lobe. In the remainder there were distortion and compression of the segmental bronchi, giving them a tapered appearance in the region of the tumor. Involvement of the bronchi begins in the smaller peripheral branches and proceeds centrally (Figs. 13, *A* and *B*). Even when the mass becomes large enough to displace and stretch the bronchi, significant bronchostenosis and atelectasis are rare. In one case,[27] submucosal collections of lymphosarcoma cells produced an irregularity in the contour of the bronchi on the bronchogram that was suggestive of the changes of chronic bronchitis.

DIFERENTIAL DIAGNOSIS

The preoperative diagnosis in most cases of pulmonary lymphosarcoma was bronchogenic carcinoma. The roentgen findings, particularly if bronchography is performed, show some differential points. The lymphosarcomata in this series were all large when first detected and most of them were in the hilar portion of a lobe. It would be extremely rare for a bronchogenic carcinoma in this location to attain such size without obstructing the bronchus and producing distal atelectasis. Wilt *et al.*[38] reviewed the bronchograms of 236 patients with bronchogenic carcinoma of all types. A bronchial block was demonstrated in almost 90 per cent of the patients, and in 213 cases the bronchogram was considered to be diagnostic of carcinoma. The clinical features of the two diseases are considerably different in most cases. Bronchogenic carcinoma usually grows more rapidly, hemoptysis is a more constant and striking feature, and histologic examination of the sputum will often show malignant cells of a specific nature.

Solitary pulmonary lesions do occur in generalized lymphosarcomatosis. Atelectasis distal to the lesion is rarely encountered and major bronchostenosis will be the exception to the rule. The distinction between primary and secondary involvement of the lungs depends on the presence or absence of lymphosarcoma elsewhere in the body. In most cases this cannot be definitely determined except at the time of autopsy or if there is long-term survival following local treatment of the pulmonary lesion.

Alveolar cell carcinoma arises in the terminal bronchiolar or alveolar epithelium and produces a true consolidation of lung by filling the alveoli with tumor cells. This can present on chest roentgenograms as a solitary mass which may be indistinguishable from lymphosarcoma. In some cases bronchograms will show evidence of a block, but in others the bronchogram will be normal. Over 70 per cent of patients with alveolar cell carcinoma will complain of cough and in an appreciable number this will be productive of a glairy, mucoid sputum. Only 7 in a series of 154 patients were asymptomatic.[31] Papanicolaou[19] has noted that this tumor exfoliates freely and abundant cells may be recovered from the sputum that are characteristic of this type of neoplasm. Watson and Smith[36] studied the sputum of 15 patients with alveolar cell carcinoma. Malignant cells were found in 9 cases and cells strongly suggestive of cancer in another 3. Roelson *et al.*[24] found positive sputa in 5 of 8 patients studied.

Lobar pneumonia produces consolidation without atelectasis, but the acute clinical history and symptoms are characteristic and it is unlikely that this would be confused with lymphosarcoma. This is not true in the cases of chronic pneumonitis such as lipoid pneumonia. The most common roentgen finding in lipoid pneumonia is that of bilateral interstitial pneumonitis. Occasionally, the disease may be localized

and appear as a single mass on chest roentgenograms. The right middle and lower lobes are the most common sites of involvement. The usual bronchographic findings show obstruction of the terminal bronchioles[13] not unlike that seen with primary pulmonary lymphosarcoma. In the exceptional case, blockage of a major bronchus may occur with lobar atelectasis. In the majority of patients, a history of chronic oil ingestion will be obtained and, in some, intracellular oil in the desquamated cells in the sputum will be demonstrated. Hall and Blades[12] report the use of a trial of irradiation to differentiate lipoid pneumonia from lymphosarcoma.

Pulmonary infarction produces an area of consolidation because of the outpouring of fluid and cells into the alveoli. Infarcts may reduce the lung volume, but atelectasis is not a prominent feature. A history of sudden chest pain, hemoptysis and shortness of breath are characteristic but not present in all cases. Roentgenograms of the chest made over a period of several weeks will differentiate this from primary lymphosarcoma. An infarct always extends to at least one, and often two, pleural surfaces; pleural effusion occurs in 13 to 40 per cent of pulmonary infarctions;[14] serial examinations will show diminution in the size of the infarct as it is organized and absorbed.

TREATMENT AND PROGNOSIS

Two of the 38 patients about whom information is available received no therapy, since the diagnosis of lymphosarcoma was made at the time of autopsy.[21,33] Four patients were considered to be inoperable because of the local extent of their disease. There was no evidence of distant metastases in any of these patients. All were treated by irradiation alone. Two died of metastatic lymphosarcoma within two years (Hall and Blades,[12] Case 1 and 3), one died of recurrent lymphosarcoma in the lungs eight years after treatment,[16] and one patient, our Case 1, is living and well nine years and ten months after therapy.

Pneumonectomy was performed in 13 cases with one death due to postoperative complications. Three of these patients received postoperative irradiation: 2 are alive and well but have been followed for less than five years (Grimes *et al.*,[11] Case 1; and Cooley *et al.*,[5] Case 3), and the third died fourteen years postoperatively without postmortem examination. Of the 9 patients treated by pneumonectomy only, 5 died within five years, 4 presumably from their lymphosarcoma (Van Hazel and Jensik,[34] Case 1; Sternberg *et al.*,[30] Case 4; Cooley *et al.*,[5] Case 5; and Weissman and Christie[37]). The fifth patient was autopsied and no evidence of lymphosarcoma was found (Rose,[25] Case 2). One patient is alive and has been followed for less than five years,[2] 2 are alive at six and seven years respectively (Hall and Blades,[12] Case 2; and Grimes *et al.*,[11] Case 2), and the last patient had two recurrences in the lung treated by irradiation. He died of coronary occlusion thirteen years and nine months after treatment.[17]

Eighteen patients had one or two lobes removed. One patient died five weeks postoperatively from a cerebrovascular accident.[26] Seven of these patients had postoperative irradiation: 5 are alive and well less than five years (Cooley *et al.*,[5] Case 1; Ergin and Kemler;[7] Sternberg *et al.*,[30] Case 5; authors' Case III; and authors' Case V), one is alive at eight and one-half years with known disease in the lung and hilar lymph nodes[4] and the seventh patient has had several additional courses of radiation therapy and is alive at twelve years.[39] Of the remaining 11 patients, one died three and one-half years postoperatively from tuberculosis, the status of his lymphoma not being known (Sternberg *et al.*,[30] Case 3). Five patients are alive less than five years (Rose,[25] Case 1; Spatt and Grayzel;[29] Sternberg *et al.*,[30] Case 5; and Van Hazel and Jensik,[34] Case 3 and 7), and 5 are alive from five to ten years (Schulze;[27] Van Hazel and Jensik,[34] Case 4; Beck and Reganis;[3] Anlyan *et al.*;[1] and authors' Case II). One of these patients developed a hilar mass four years after lobectomy which was irra-

diated,[1] and a second has known disease in the lung and hilar lymph nodes at eight and one-half years.[4]

Case IV in this report had one lesion removed by wedge resection and a second treated with irradiation. She died five months postoperatively.

COMMENT

Primary lymphosarcoma of the lung is a slow growing tumor and widespread dissemination is uncommon. Two patients (authors' Case III; and Schulze[27]) had been observed for five years without treatment before surgery. In both cases, the lesions enlarged slightly over this period. Lobectomy was performed and both are alive and well two and one-half years after operation. The mistake in each case, leading to the delay in treatment, was to consider the lesion nonmalignant because of the patent bronchi within the mass.

Bronchoscopy has not been of much assistance in establishing the diagnosis preoperatively. It has been shown in cases of bronchogenic carcinoma that biopsy of normal appearing mucosa may reveal submucosal infiltration by malignant cells.[22] As lymphosarcoma is frequently found beneath the bronchial mucosa, it is possible that blind biopsies of the bronchus leading to the involved segment may contribute more positive findings.

Chest roentgenograms may be misleading when attempting to assess the extent of lung involvement. In many of the cases adjacent lobes, pleura or mediastinum have been involved, although the lesion appeared on roentgenograms to be a fairly well localized mass. Robbins[23] has noted that at times the pathologist finds lymphomatous foci in the lung as large as 1 cm. in diameter which were not seen on roentgenograms. When the hilar or mediastinal lymph nodes are involved, they are usually not sufficiently enlarged to be recognized roentgenologically.

Adequate follow-up of a sufficient number of cases is not available to enable us to evaluate the various forms of treatment. At present, the definite diagnosis of lymphosarcoma is generally made at the time of thoracotomy. If the lesion is considered resectable, lobectomy or pneumonectomy seems to be the reasonable mode of treatment. However, because of the microscopic spread of the tumor, the inability of the surgeon to always recognize lymph node involvement (our Case II), and the radiosensitivity of lymphosarcoma, postoperative irradiation of the lung and mediastinum seems to be indicated.

SUMMARY

1. Primary lymphosarcoma of lung is a relatively rare lesion presenting as a mass in the lung, but is a distinct entity with some characteristic roentgen findings which are of diagnostic value.

2. Five new cases, histologically proved, are added to the 34 cases previously reported in the literature.

3. Approximately one-third of the 39 patients discussed had no symptoms. In the remaining two-thirds, cough, hemoptysis and chest discomfort were the most frequent findings. Recurrent pneumonitis was common.

4. Bronchoscopy was normal in 12 of 29 cases. Extrinsic pressure, granularity with inflammatory changes, friable mucosa or ulceration may be seen. Biopsy of apparently normal mucosa in the involved segment is suggested to find possible submucosal involvement in a greater number of cases.

5. Sputum and bronchial washings were negative for malignant cells in 11 of 14 cases so studied.

6. Roentgen findings are a homogeneous mass, more centrally than peripherally located, without hilar or mediastinal involvement, and possibly showing slow growth if observed over a long period of time. Atelectasis is rare; patent bronchi may be demonstrated by the "air bronchogram" or by contrast bronchography.

7. The roentgen appearance and clinical course frequently can be differentiated from those of bronchial carcinoma, alveolar

cell carcinoma, lobar pneumonia, lipoid pneumonia and pulmonary infarction.

8. Pulmonary resection, if feasible, with postoperative irradiation, and primary irradiation if thoracotomy demonstrates nonresectability, constitute the treatments of choice.

Murray G. Baron, M.D.
The Mount Sinai Hospital
11 E. 100 Street
New York 29, New York

The authors express their appreciation to Dr. Murray Abel for reviewing the pathologic material and confirming the previous diagnosis of lymphosarcoma in the 5 cases here reported, and to Dr. Cameron Haight for permission to include Case II. The radiation therapy in Cases I, IV and V was administered by Dr. Isadore Lampe and his staff.

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Vol. 85, No. 2

ACCESSORY DIAPHRAGM

A CASE REPORT

By GORYUN NIGOGOSYAN,* *and* AHSEN OZARDA†
BUFFALO, NEW YORK

AN ACCESSORY diaphragm, a rare anomaly, consists of a second leaf of diaphragm which is located in the right chest cavity and separates all or part of the lower lobe from the remaining lung. Two cases have been reported in the current medical literature,[2,3] and we are adding a third case.

REPORT OF A CASE

A fifty-seven year old white woman died from ascending pyelonephritis resulting from ureteral obstruction by scar tissue twenty-one years after a squamous cell carcinoma of the cervix had been treated by radium.

As a wholly unrelated finding, an accessory diaphragm was found in the right hemithorax. This diaphragm was situated in the oblique fissure and formed a posterolateral pouch in which the right lower lobe was contained. Its insertions were medially the pericardium; anteriorly the diaphragm, about 3–4 cm. from its anterior insertion; laterally the chest wall starting at the level of the seventh rib, and posteriorly the chest wall at the level of the fifth rib near the spine. Its course followed the oblique fissure, thus it had formed a posterolateral pouch in the right thoracic cavity (Fig. 1, *A* and *B*).

The bronchovascular elements were normal in their origin and distribution. However, those to the right lower lobe passed through the accessory diaphragm by way of a 2×3 cm. semilunar opening located near the mediastinum. The leaf was composed of connective tissue 1 mm. thick except at the rim of the mediastinal opening where it was approximately 2–3 mm. thick and contained skeletal muscle all along the free edge. The true diaphragm showed normal structure, location and attachment.

In addition to this diaphragmatic anomaly, the right lung showed minor abnormalities. Two supernumerary lobes, about 2.5 cm. in length, arose from the apex of the right lower lobe and were incompletely separated from the lower lobe by shallow fissures. The right lower lobe did not show any bronchiectasis, fibrosis or other pathologic findings. The left lung was not remarkable.

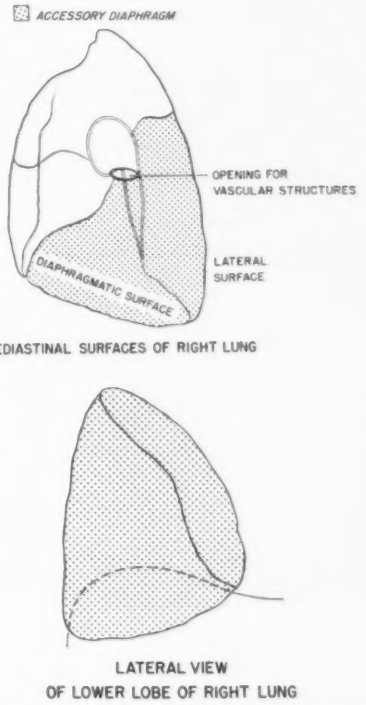

FIG. 1. (*A* and *B*) Diagrams of the accessory diaphragm and its relation to the right lung.

Roentgenographically, the right diaphragm was elevated and the oblique fissure was accentuated and thickened (Fig. 2, *A* and *B*). Anteriorly, the right diaphragm was about 4.5 cm. higher than the left. The contour of the diaphragm was regular. The oblique fissure was shown clearly as a band-like soft tissue shadow between the fifth and sixth ribs in the intercostal space. Anterolaterally, the same fissure was seen as a linear density at the upper margin of the fourth rib.

* Formerly, a resident in Pathology at Roswell Park Memorial Institute. Present address: Harper Hospital, Department of Pathology, Detroit, Michigan.
† Senior Cancer Radiologist, Department of Nuclear Medicine, Roswell Park Memorial Institute.

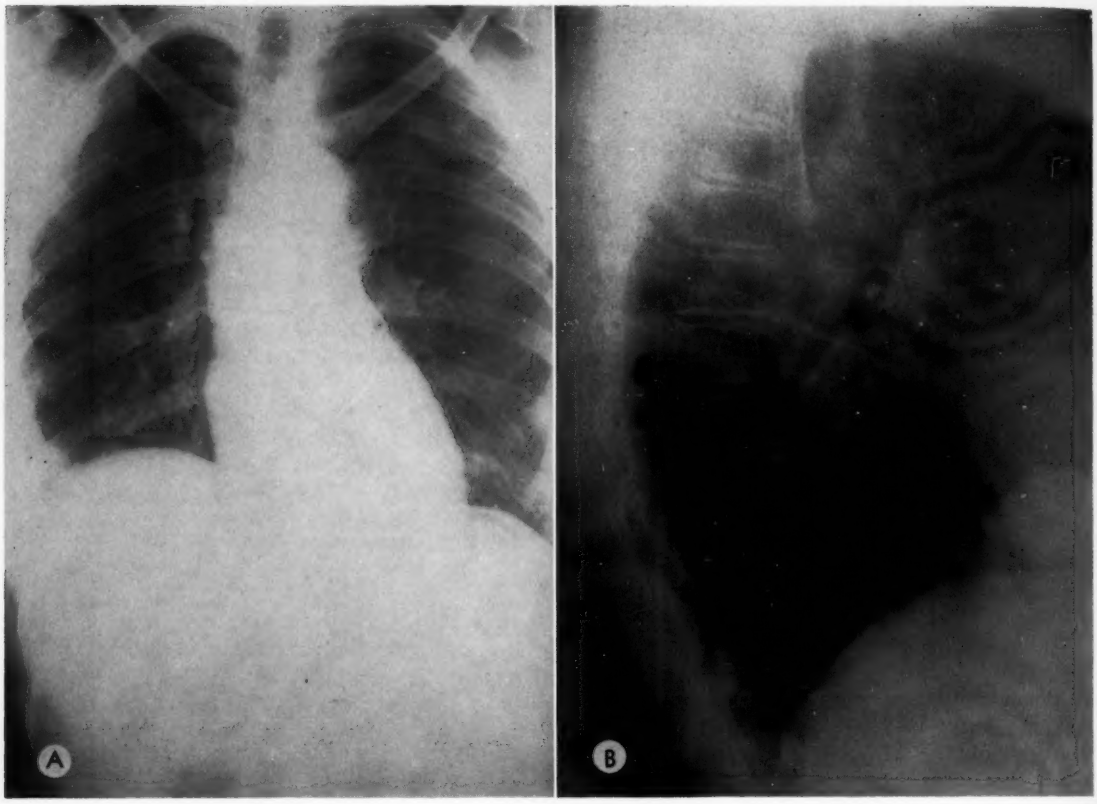

FIG. 2. (*A* and *B*) Posteroanterior and lateral roentgenograms showing elevation of the right diaphragm and thickening of the oblique fissure.

DISCUSSION

For a roentgenologic differential diagnosis, the findings of an elevation of the right diaphragm and thickening of the oblique fissure without evidence of any other lesion in the right chest indicate that an accessory diaphragm must be considered, especially when the patient has been followed for a long period of time without any change in the roentgenographic appearance.

We have been able to find two reports in the literature that give findings with minor differences but similar to those presented in this report. Drake and Lynch[2] discussed the case of a twenty-six year old male where only a small part of the right lower lobe was found in the pouch formed by the accessory diaphragm. In the patient of Sappington and Daniel,[3] a seven year old girl, an accessory diaphragm separated the right lower lobe from the upper lobe, as was noted in our patient.

It is noteworthy that, in the 2 reported cases, bronchiectasis of the right lower lobe led to lobectomy. Our patient, on the other hand, showed only supernumerary lobes. The absence of bronchiectasis in our case may be explained by the anatomic findings; the accessory diaphram was composed of fibrous tissue and very little muscle. In the previous reports, both patients had accessory diaphragms that were muscular. Contraction of the muscle probably caused incomplete aeration and intermittent obstruction of the bronchioles with resulting infection and bronchiectasis. Since little or no muscle was present in the accessory diaphragm of our patient, this mechanism did not function.

A case reported by Allen[1] was related,

but not similar, to our case. It consisted of transpleural muscles between the sixth rib and the central tendinous part of the right diaphragm, situated in the oblique fissure. This represents an incomplete but muscular accessory diaphragm.

SUMMARY

A case of accessory diaphragm is reported in a fifty-seven year old white female. It consisted of a fibrous membrane separating the right lower lobe from the rest of the lung. Its roentgenologic appearance is briefly discussed.

Ahsen Ozarda, M.D.
Radiotherapy Department
The Johns Hopkins Hospital
Baltimore 5, Maryland

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HORIZONTAL LAMINAGRAPHY: A SUPPLEMENTAL DIAGNOSTIC METHOD IN TUMORS OF THE LUNG, ESOPHAGUS AND MEDIASTINUM*

By HELMUT F. GATZEK, M.D., *and* FRANZ P. LESSMANN, M.D.
BUFFALO, NEW YORK

HORIZONTAL laminagraphy as a variation of body section roentgenography provides an anatomic cross section of a patient in a horizontal plane at any desired level.

Although the roentgenologic diagnosis of chest lesions is usually made on the basis of conventional posteroanterior and lateral roentgenograms, this method falls short in the evaluation of the mediastinum. The posteroanterior roentgenogram presents a superimposed view of the thoracic spine, vascular structures and sternum with the embedded trachea. Bulging of the margin

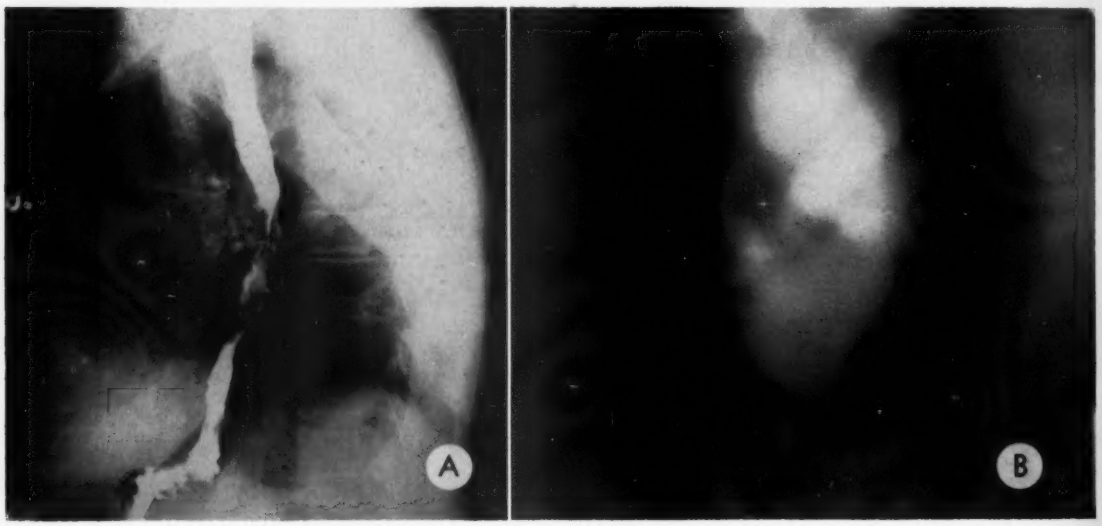
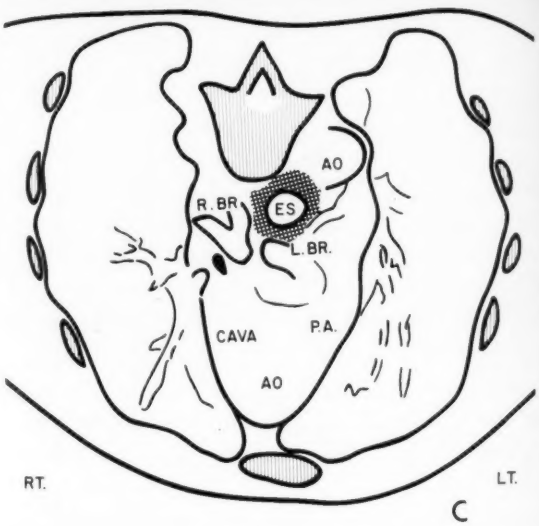


FIG. 1. Case 1. A seventy-five year old white male was referred to the institute with the diagnosis of carcinoma of the esophagus in the mid-portion (*A*). Azygography showed a complete outlining of the azygos system with some minor indentation in the upper one third, not very conclusive for extrinsic pressure, but important enough to warrant further investigation.

Horizontal laminagram (*B* and *C*), just below the bifurcation, does not show any signs of mediastinal lymph node involvement.

At surgery, the tumor was completely resected, and no mediastinal lymph node involvement was found.



* From the Department of Diagnostic Radiology, Roswell Park Memorial Institute, Buffalo, New York.

and alteration of the position and caliber of the trachea are the only easily recognizable features. Additional information is gained with oblique views, Bucky studies, vertical laminagraphy, fluoroscopic examination of the opacified esophagus and thoracic angiography. A further method to examine the posterior mediastinum is the azygos demonstration by intra-osseous injection,[9,17,21,29,31,34] which was performed in some of our cases.

Horizontal laminagrams disclose the spatial relationship and topography of the mediastinal organs, lungs and pleura better

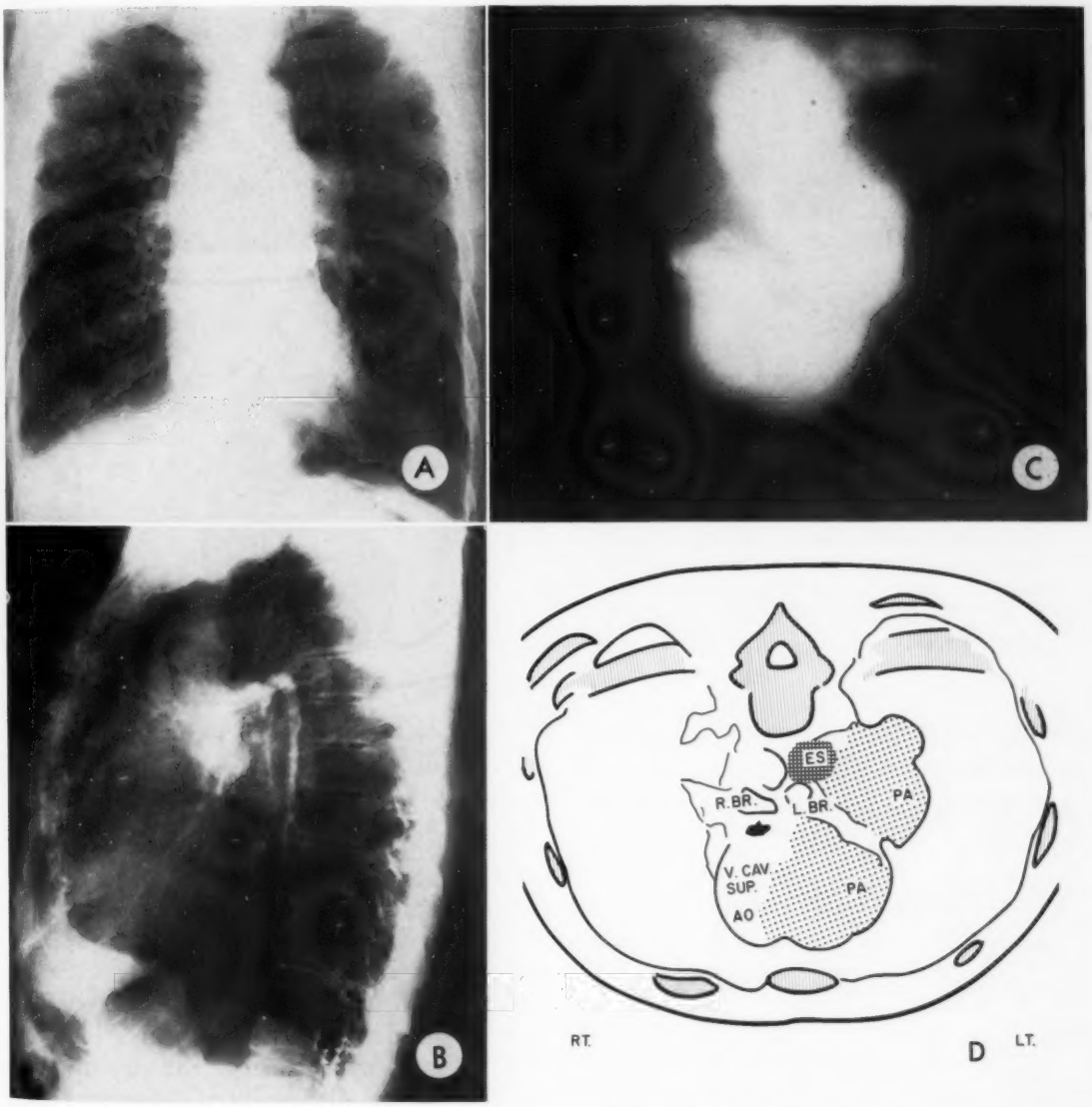


Fig. 2. Case 11. In this sixty-five year old man with a carcinoma of the mid-esophagus, the conventional roentgenogram (*A*) of the chest shows a prominent left hilar mass suggestive of tumor or a prominent left pulmonary artery.

(*C* and *D*) Horizontal laminagram at the level just below the carina shows the pulmonary artery and particularly its left branch to be markedly enlarged. No hilar or mediastinal lymphadenopathy is seen. (*B*) Azygography demonstrates a patent azygos and hemiazygos system.

At surgery the tumor was found confined to the esophagus. Pulmonary stenosis and post-stenotic dilatation of the left pulmonary artery were evident.

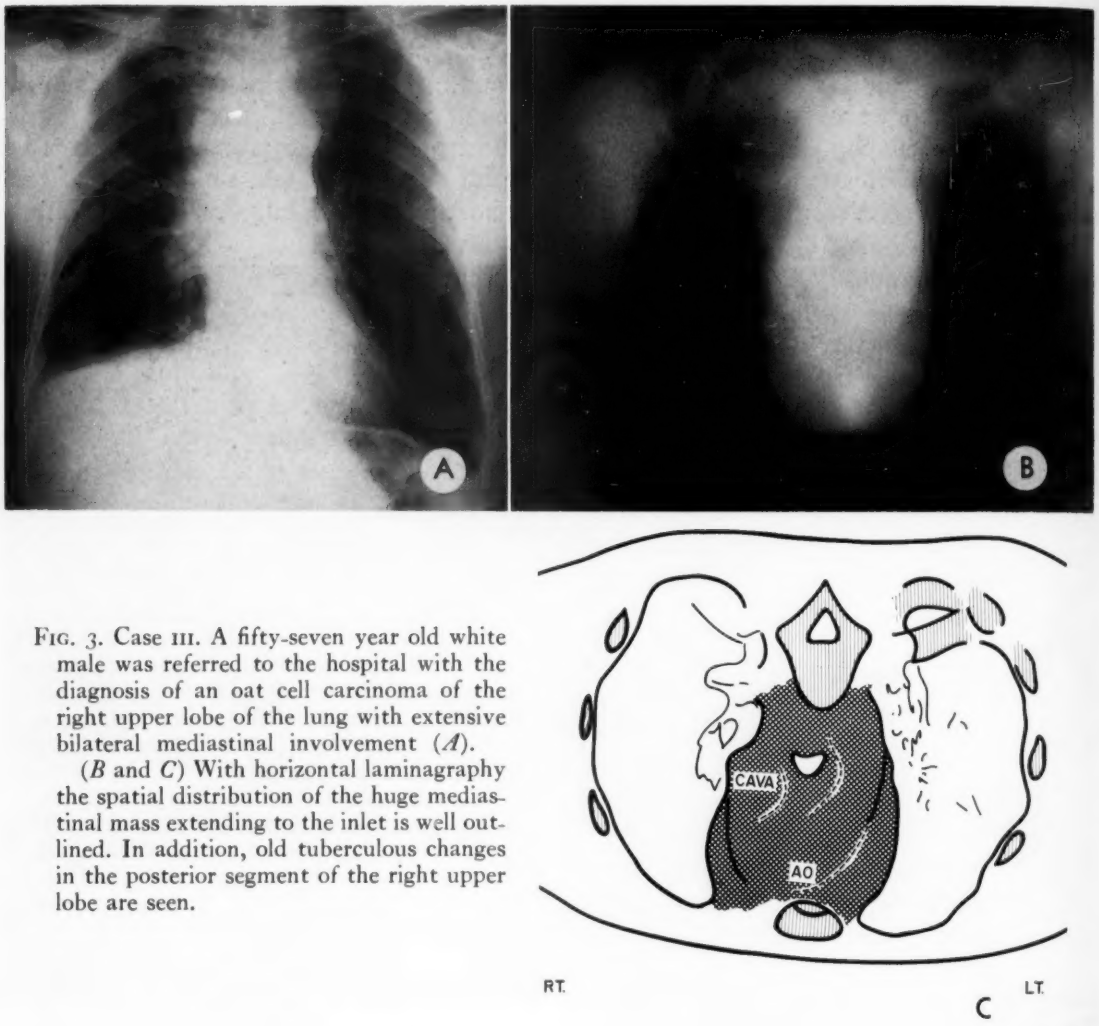


FIG. 3. Case III. A fifty-seven year old white male was referred to the hospital with the diagnosis of an oat cell carcinoma of the right upper lobe of the lung with extensive bilateral mediastinal involvement (*A*).

(*B* and *C*) With horizontal laminagraphy the spatial distribution of the huge mediastinal mass extending to the inlet is well outlined. In addition, old tuberculous changes in the posterior segment of the right upper lobe are seen.

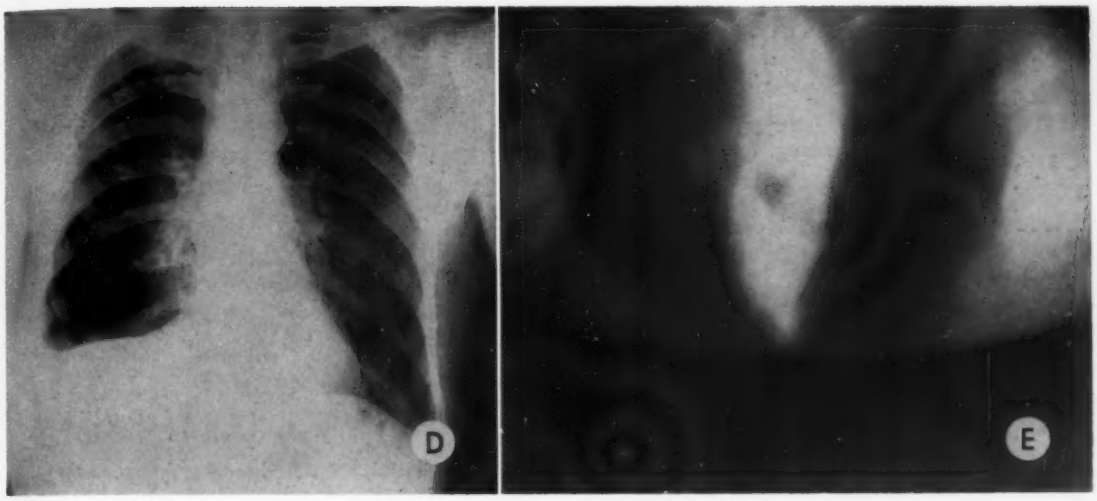
than the above mentioned methods and demonstrate more adequately otherwise obscured areas.[3]

Stimulated by Kieffer[14] of Norwich, Connecticut, the first workable laminagraph was built by Watson,[38] who was also the first to publish his findings. European investigators such as Vallebona and coworkers,[35,36] Amisano and his colleagues,[1,2] Gebauer and Schanen,[12] and others[15,16,20] promoted this method and an extensive bibliography has accumulated since, particularly in the Italian literature.[4,6,7,28]

Roswit *et al.*[25,26] and Wilk[39] in the United States contributed from their experience with this technique, and are impressed by its merits as a valuable tool in diagnosis and in treatment planning. In their papers and in that of Stevenson,[30] the efficiency of this method is described and an explanation of its physical principles is outlined.

For horizontal laminagraphy, a special laminagraphic unit is required, consisting of a chair and a cassette holder which rotate simultaneously in the same direction at the same speed during the exposure. A number of suitable units of different European makes are available. We used a laminagraph of our own construction which was built on the principles of commercially known units.

The exposure of the roentgenographic film is made in an angle of incidence of 23° at a focus-film distance of $7\frac{1}{2}$ feet, during a



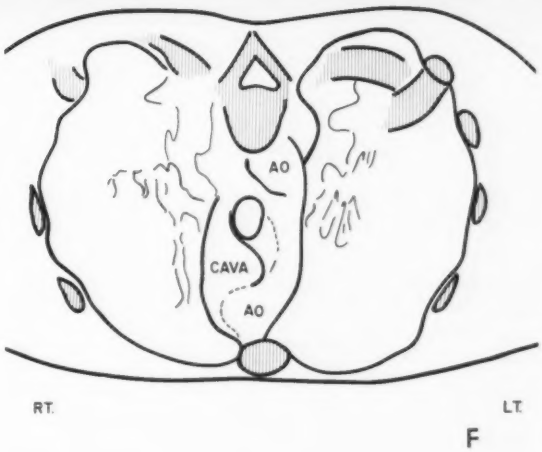
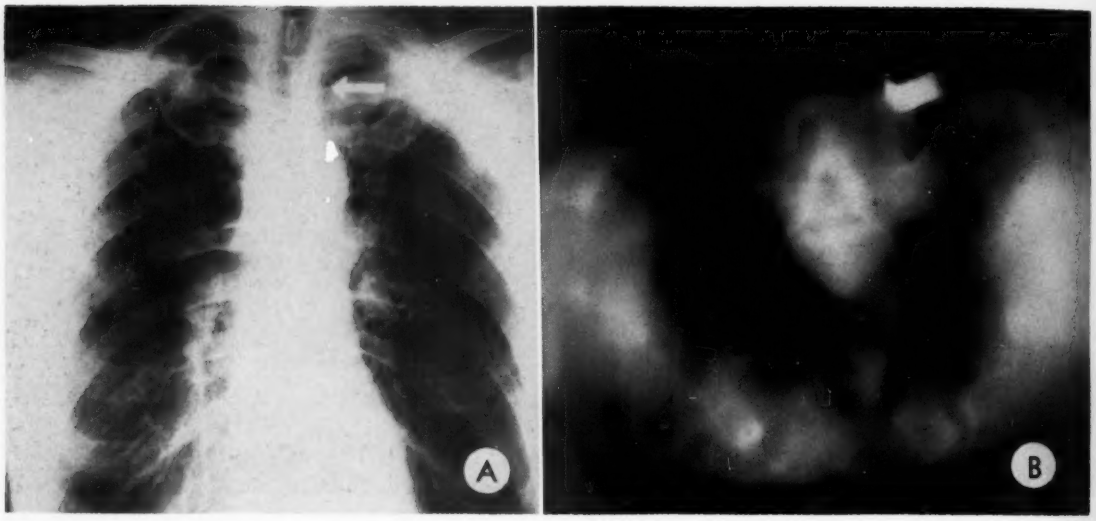


FIG. 3. Case III. (*D–F*) The control examination after radiation therapy shows complete regression of the mediastinal mass. This was confirmed at autopsy three months later.

complete revolution of patient and cassette. The thickness of the represented section is, according to Vieten,[37] about 0.3 cm. and depends on the angle of the incident beam. The technical factors used are: 65–80 kvp., 100 ma., 3 second exposure, high speed screens. The radiation dosage the patient is exposed to is 0.4 r (air) and has been considerably reduced with films and screens of increased sensitivity.[39,40] Proper alignment of the unit and narrow collimation of the beam[13] determine the quality of the laminagram. Exposures with a partial rotation as advocated by Lindblom[18] increase detail at the expense of increased blur from adjacent structures.

Horizontal laminagrams obtained in this fashion correspond with the descriptive cross section as used in an anatomic atlas.[10] They are free from distortion, and the blur effect commonly seen in conventional laminagrams is considerably less pronounced. Particularly dense structures in the vicinity of the represented section, however, can produce blur shadows and obscure the fine details which are known as "induced deformations."[12,24,33] Due to the tube-object-film distances, horizontal laminagrams show an enlarged image. The magnifying factor is constant for the set-up used, so that the actual size of any given structure can be measured with proportional calipers. Where life-size laminagrams are required, as for outlining and computing purposes in radiation therapy[11,12,22,25,32,35] or for the measurement of the volume of organs,[5,8] reduction to normal size is possible. Different devices have been described for this



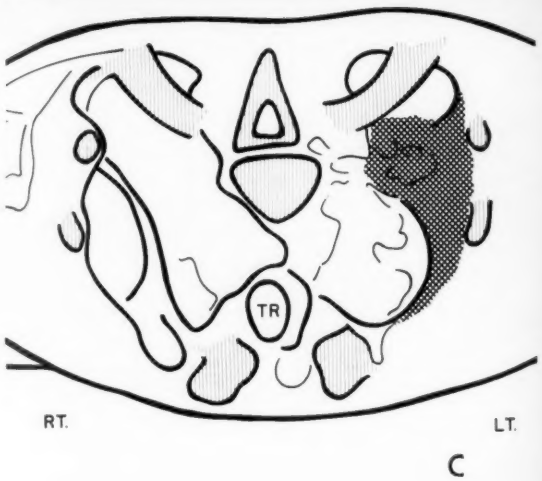


FIG. 4. Case IV. This is the case of a fifty-seven year old man with the clinical diagnosis of a left superior sulcus tumor (*A*) confirmed by biopsy.

(*B* and *C*) Horizontal laminagram at the level of D_3-sternal notch shows a dense tumor mass about 8 cm. in extension attached to the lateral thoracic wall. There are no definite signs of mediastinal involvement. Incidental findings are fibrotic changes in the right upper lobe with slight retraction of the trachea towards the right. Sections through the tumor bearing area serve for therapy planning.

purpose.[23,26,39] We used a simple camera lucida which admits standard 14×17 inch roentgenographic films.

The level at which laminagrams were taken is readily identified by the structures reproduced on the film (bifurcation, sternoclavicular joints, etc.). Wilk[39] uses metallic rods of different lengths embedded in plastic material and fastened to the patient's chest wall. Other methods using similar devices are described.[11,26,41] All of them help to determine the section level and to repeat identical follow-up roentgenograms.

The present paper is published to report about our experience with horizontal laminagraphy. The objective of this investigation was: (1) to determine the usefulness of this method in tumors involving the lung, esophagus and mediastinum and (2) to study tumor extension and its differentiation from concurrent pathology. Our results are based on the evaluation of 68 cases of which all but 2 were proved histologically. The results from horizontal laminagraphy and conventional examination were correlated with the clinicopathologic findings. The patients submitted to this study were selected from a large number of cases treated in this institute. They represented either diagnostic problems or were referred for cross section roentgenography through the tumor bearing area for radiation treatment planning and dosage calculation.

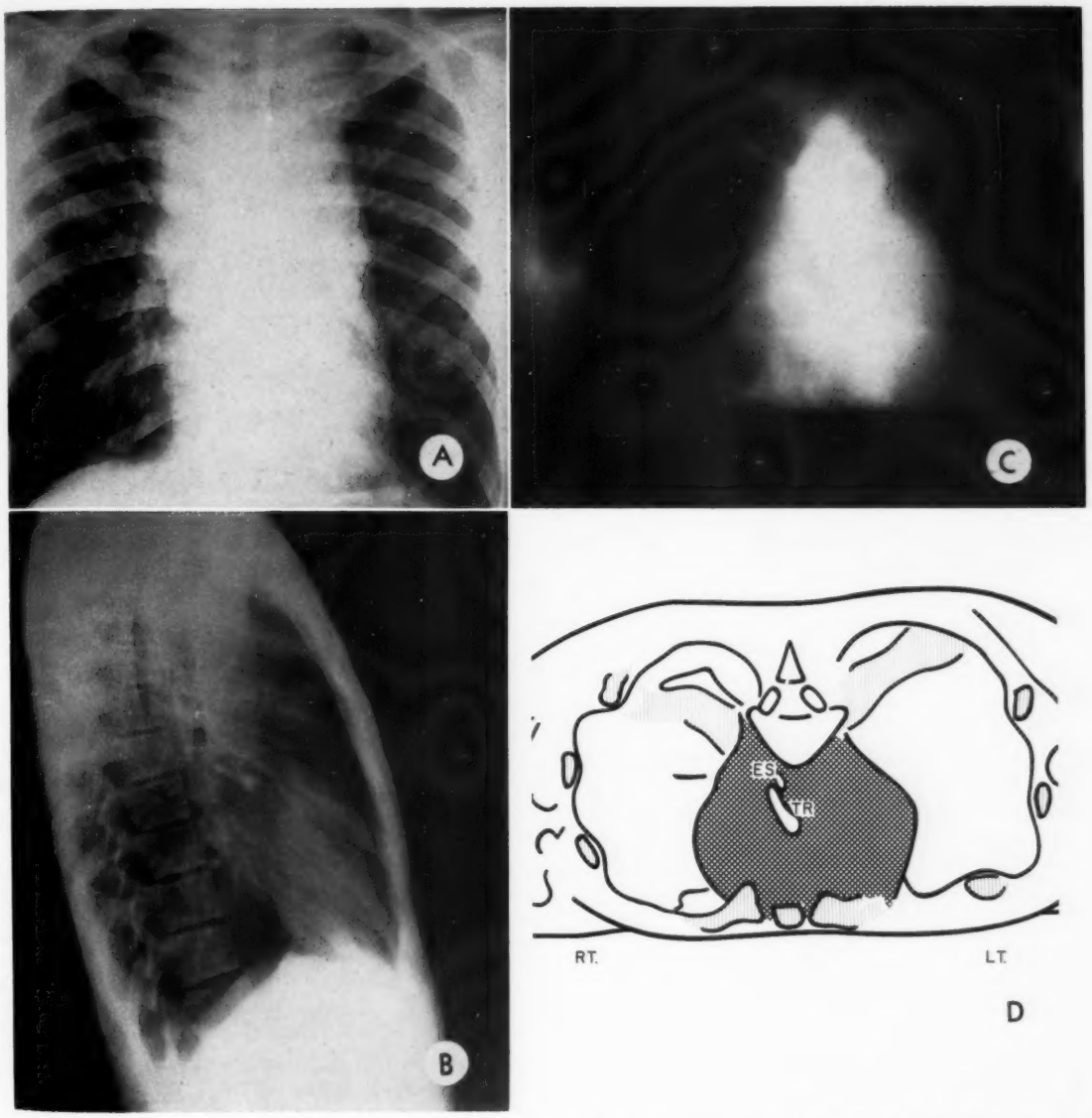


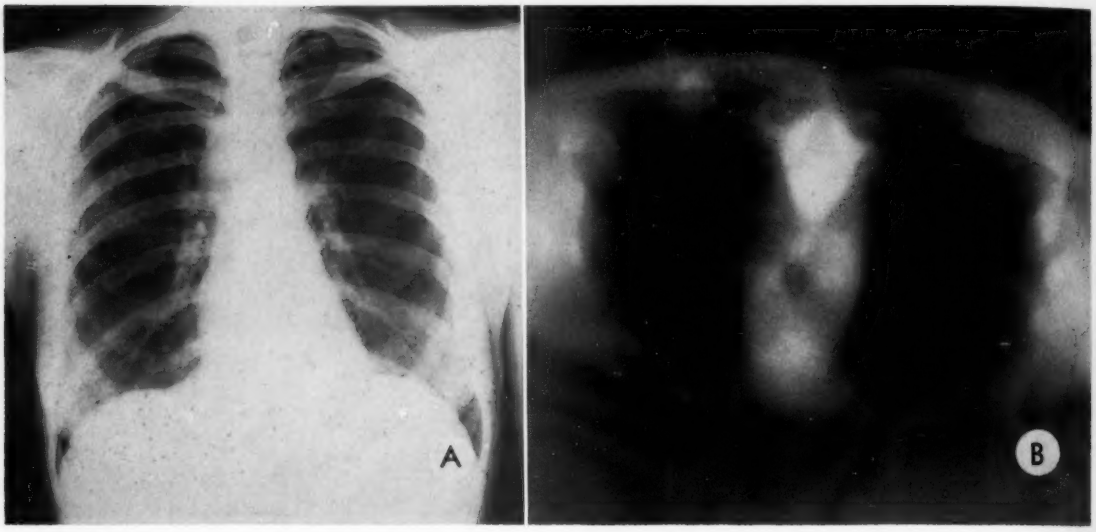
Fig. 5. Case v. This was a twenty year old white male with the diagnosis of mediastinal Hodgkin's disease. Posteroanterior and lateral chest roentgenograms (*A* and *B*) show huge bilateral mediastinal polycyclic masses.

(*C* and *D*) Horizontal laminagram reveals good outlining of the mass in the 3 compartments of the mediastinum with encroachment of the trachea.

DISCUSSION

The great number of different methods developed for the differential diagnosis of lesions of the chest and mediastinum show clearly the difficulty of this problem. Several investigators[2,12,36,39] have shown the usefulness of horizontal laminagraphy as a complement to other roentgenographic procedures.

In 27 cases of bronchogenic carcinoma, we have found that the tumor mass could be promptly differentiated from surrounding atelectases and effusions by virtue of their different density. A shift of the mediastinum as well as hilar involvement was also well seen. In 11 cases, distortion of the trachea due to extrinsic pressure and narrowing of its lumen was observed more



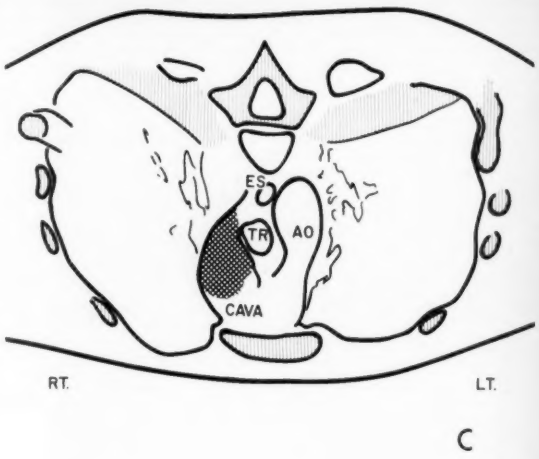


FIG. 6. Case VI. A forty-four year old housewife with the diagnosis of Hodgkin's disease had been treated with radiation therapy to various regions, including the mediastinum, four years ago. At the time of this examination, the patient was asymptomatic. However, the conventional posteroanterior roentgenogram (*A*) shows a well-defined, convex mass at the level of the right main bronchus extending in a vertical direction.

(*B* and *C*) Horizontal laminagram shows this mass with well-defined borders lying to the right of the esophagus, anterior to the thoracic spine and extending towards the vena cava superior. The diagnosis of a prominent azygos vein was made, most likely due to postirradiation fibrosis. This was confirmed by azygography.

distinctly than by vertical laminagraphy. Three patients had the additional finding of cavity formation which in one case showed extension to the lateral pleural space not seen by vertical laminagraphy.

In carcinomas of the esophagus, the choice of treatment is determined by the topographic relation of the tumor and the presence of lymph node involvement. Although the diagnosis is based on the conventional barium swallow and esophagoscopy, horizontal laminagraphy has shown to be an aid in analyzing the size of the tumor and its relation to adjacent structures. Twenty-one cases with esophageal tumors were examined. In 12 cases, the lesion was confined to the upper third and in 8 of these a displacement and encroachment of the trachea were visible. Of course, in all the lesions, the exact extension of the tumor mass could be demonstrated. In 6 cases of lesion of the mid-third of the esophagus, the determination of expansion in regard to the related structures, as pulmonary vessels, and the main bronchial system was found to be most valuable and of benefit for the treatment planning. It is our impression that in these lesions, horizontal laminagraphy is superior to all conventional methods. In the 3 cases with lesions of the lower third of the esophagus, the extent of the tumor was well demonstrated, but no additional information was obtained. Due to the absence of any dense

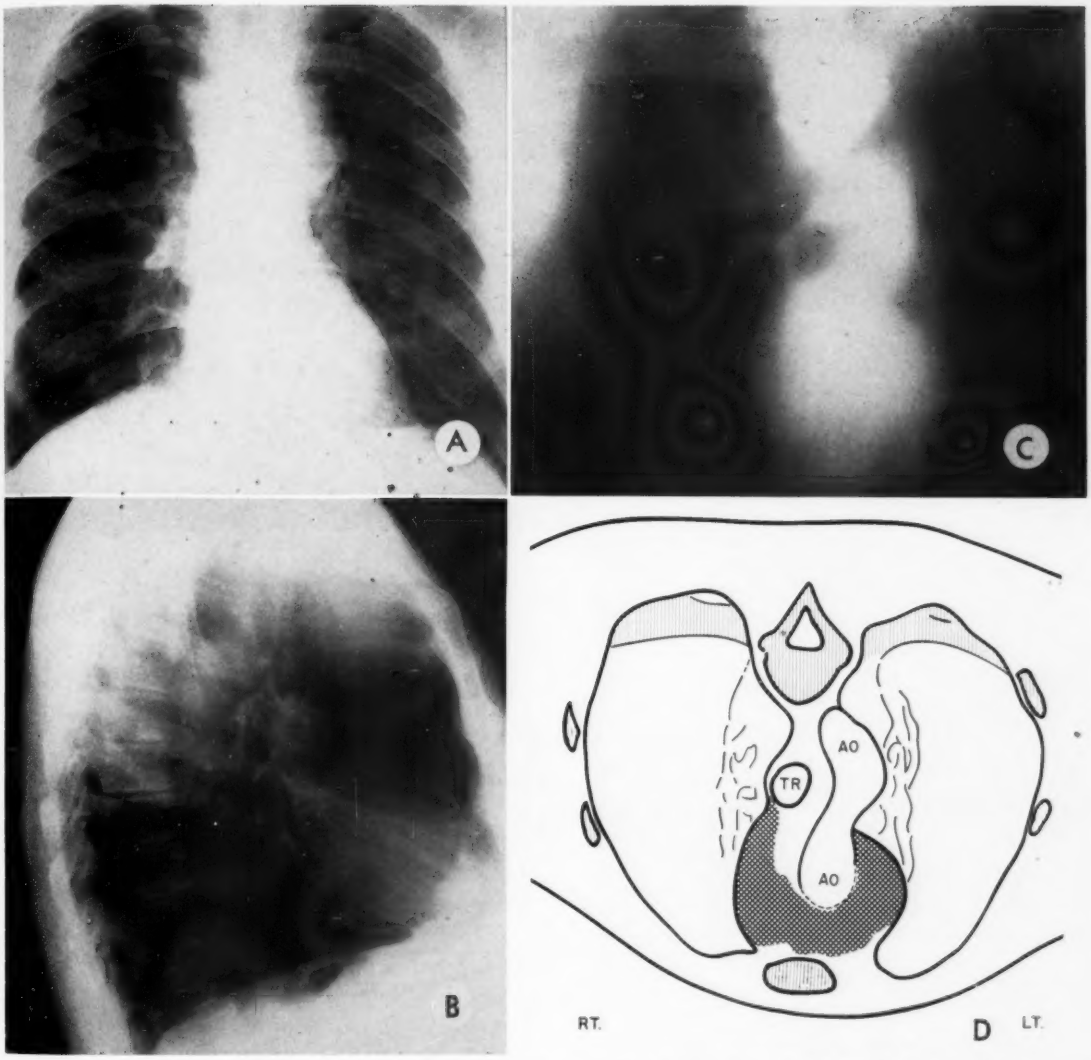


Fig. 7. Case VII. This white male, sixty-nine years of age, was admitted to the hospital for evaluation and treatment of an anterior mediastinal mass. The anterior and upper borders of the tumor appear well defined and symmetric on the conventional roentgenograms (*A* and *B*). Yet the extent of the mass in its posterior direction and its relation to the great vessels cannot be demonstrated with these procedures. (*C* and *D*) Horizontal laminagram shows a well-delineated mass in the anterior mediastinum measuring about 9 cm. across, encompassing the ascending aorta, the superior vena cava and extending towards the trachea. No signs of hilar lymphadenopathy are present.

At surgery a benign encapsulated thymoma was found.

organic structures in the retrocardiac space, a tumor can be easily visualized in this area. An attempt was also made to study the barium-filled esophagus during the examination but was not very successful due to the considerable blurring of the heavy contrast medium. Stevenson[30] has used a nasogastric tube filled with opaque material which gave him a satisfactory orientation on the roentgenograms. Other authors[19,22] report in the Italian and French literature the usefulness of a pneumomediastinum during the examination which enables them to outline the outer esophageal wall.

In the majority of mediastinal tumors,

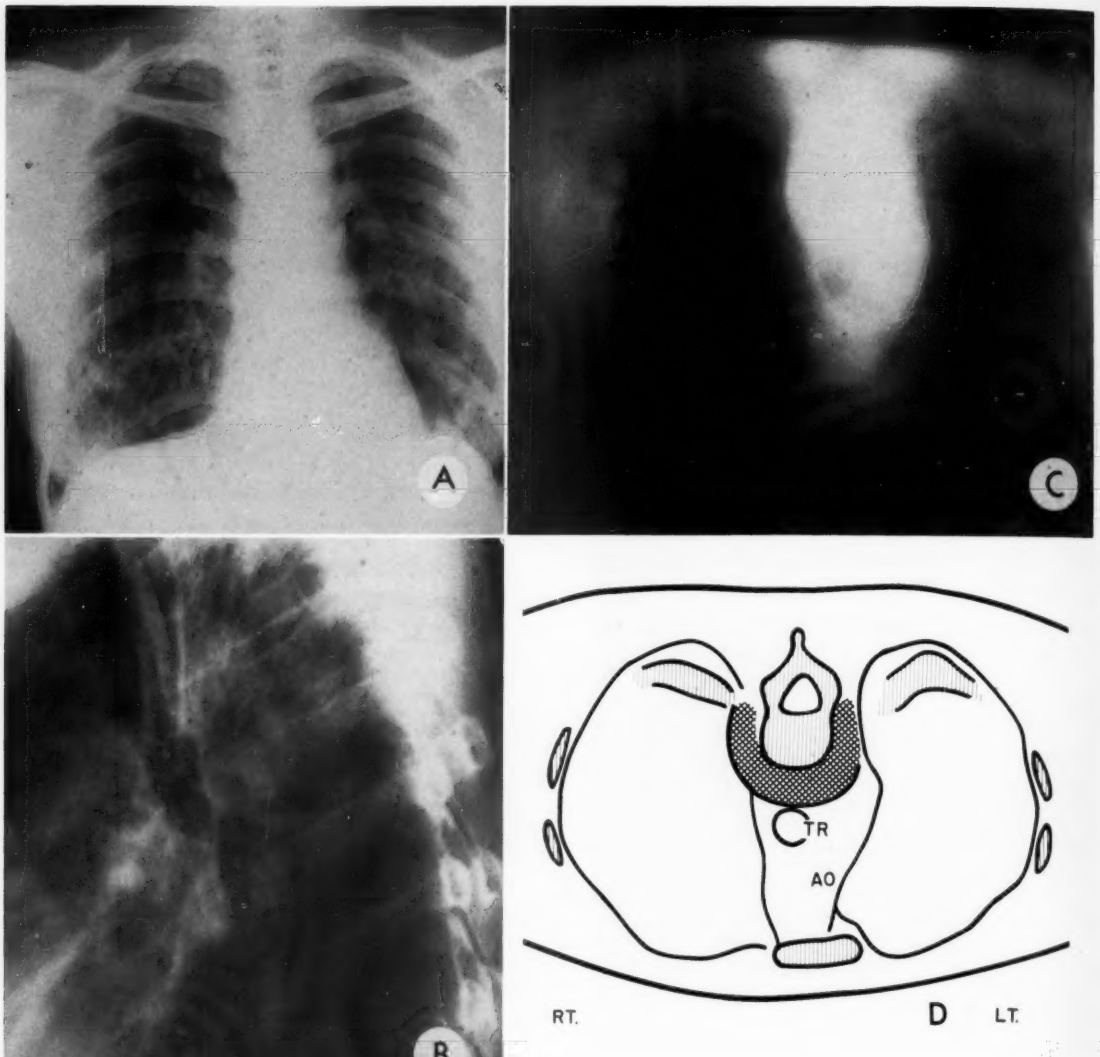


FIG. 8. Case VIII. This forty-three year old white housewife was referred to this institute with the diagnosis of Hodgkin's disease.

(*A* and *B*) Posteroanterior and lateral roentgenograms reveal numerous nodular infiltrations in both lungs and a slight bilateral mediastinal widening at the infraclavicular level. On the lateral roentgenogram, a wedge shaped compression of D_4 is noted.

(*C* and *D*) Horizontal laminagram taken at the level of the fourth dorsal vertebra reveals a well-delineated localized soft tissue mass engulfing this vertebral body in a U-like fashion, indicating the presence of a soft tissue mass. The mid- and anterior mediastinal compartments are normal.

identification is readily made by conventional roentgenographic procedures and horizontal laminagraphy does not offer significant additional information. However, in isolated cases with a differential diagnostic problem, a more comprehensive view of the three mediastinal compartments can be obtained. In the 20 cases studied with this method, important diagnostic details could be attained.

The appreciation of the appearance of the tumor, its boundaries, localization and sometimes its symmetry furnished diagnostic clues in spine involvement and in

thymomas. A prominent azygos vein could be differentiated from tumor recurrence. Because of the difference in densities between solid tumor masses and areas of fibrosis and atelectasis, recurrent disease could be ruled out. Displacement and encroachment of the trachea were more accurately outlined, especially by the observation of changes in the size and the shape of the tracheal lumen. Another advantage of this method lies in the clinical and therapeutic follow-up of patients where control examinations carried out after chemotherapy or irradiation serve as an objective record in evaluating the change in size of a tumor mass.

SUMMARY

Horizontal laminagraphy as a supplemental diagnostic method was employed to determine its usefulness in the evaluation of tumors of the lung, esophagus and mediastinum. Sixty-eight cases were studied, of which 27 were bronchogenic carcinoma; 21, esophageal carcinoma and 20, lymphomas. The findings are presented and correlated with the information gained by conventional roentgenographic procedures. Clear delineation of topographic-anatomic detail with this method permits detection of relatively minor deviations from normal. Not only are gross structures well outlined but the relationship of a tumor mass can be more adequately determined, making this procedure a valuable diagnostic aid in certain cases.

Franz P. Lessmann, M.D.
Diagnostic Radiology
Roswell Park Memorial Institute
Buffalo 3, New York

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X-RAY IMAGE INTENSIFICATION WITH A LARGE DIAMETER IMAGE INTENSIFIER TUBE*

By WILFRID F. NIKLAS
CHICAGO, ILLINOIS

WHEN x-rays penetrate an object, the local x-ray attenuation depends on both the thickness and atomic number of the elements forming the object under scrutiny. Thus, the intensity pattern in the x-ray beam after penetration of the test object contains information concerning the structure of the object.

This structural information is generally made visible by a fluorescent screen converting the x-rays into visible light. The intensity pattern of the x-ray beam can now be recognized as a brightness pattern on the fluorescent screen.

The x-ray doses used for medical application may not exceed certain limits, as otherwise physiologic and genetic damage results. This limitation, together with the relatively low intrinsic efficiency of x-ray sensitive phosphors, sets light levels on the fluorescent screen which are at best comparable to the illumination of a landscape by the full moon.

The observer of such a low brightness pattern is forced to utilize rod rather than cone vision, leading to decreased detail perceptibility. Thus, the observer is unable to perceive all information originally contained in the x-ray beam.

While the physiologic limitation of the human eye inhibits the full utilization of the intelligence contained in the x-ray beam, a further physical limitation is represented by the "quantum fluctuations."

As discussed in detail by Tol, Oosterkamp and Proper,[7] the perceptibility of contrast and detail is connected by the relations:

$$C = (B_2 - B_1)/B_1 = k/\sqrt{\overline{N}} \qquad (1)$$

wherein C = contrast; B_1, B_2 = brightness of two information elements; $\overline{N}$ = average number of radiation quanta incident on each information element per second; and k = constant.

X-ray quanta are emitted from the target in the x-ray tube in statistical distribution with time as the independent variable. The random nature of quantum emission becomes less visible to the human eye as the number of quanta per second, incident on the area of scrutiny, increases. The number of quanta may be increased by increasing the area of scrutiny (decreasing detail perceptibility) or by increasing the radiation intensity.

Equation 1 represents the fundamental limitation of contrast-detail perceptibility due to quantum fluctuations. It is not possible at present to circumvent this limitation by other means than storage, and with this approach the length of the storage time, necessarily longer than the accumulation time of the human eye, reduces the time resolution of the information obtained.

The average number of quanta $\overline{N}$ to be used in Equation 1 is the lowest number of quanta per second per unit area found anywhere in the image converting and intensifying system.

In a simple chain, consisting of x-ray emitter-object-fluorescent screen-observer, the "quantum sink" lies in the eye of the observer. In an image intensifying system, the quantum sink is located generally, but not always, in the element of first energy conversion (x-rays to visible light). Furthermore, the quantum sink is now not as deep as for image conversion without intensification. Thus, the contrast-detail perceptibility is increased at a given x-ray intensity.

Cinefluorography is widely used in modern roentgenology.[2] The application of

* From the Rauland Corporation, Chicago, Illinois.

cinematography to radiology leads to a substantial increase in x-ray doses with the disadvantages mentioned above. The available number of light quanta in cinefluorography utilizing standard fluoroscopic screens decreases with increasing frame rate, imposing a limitation on the application of cinefluorography. This disadvantage can be remedied by the use of image intensification.

The application of television techniques to roentgenology offers new possibilities in medicine. Television fluoroscopy of manageable complexity generally requires image intensification previous to the television pick-up device.

The advantages of image intensification in radiology may be summarized as follows: (a) increased contrast-detail perceptibility at maintained radiation level or (b) maintenance of contrast-detail perceptibility at reduced radiation level; (c) extension of the field of application of monoplane and biplane cinefluorography; and (d) reduction in the complexity of equipment in television fluoroscopy.

SURVEY OF X-RAY IMAGE INTENSIFYING SYSTEMS*

The proposed or existing x-ray image intensifying systems may be divided into three groups: (1) electronic systems; (2) solid state systems; and (3) vacuum tube systems.

The principles of these three types of x-ray image intensifying systems are summarized below.†

1. ELECTRONIC SYSTEMS

The electronic intensifying systems convert the information contained in the x-ray beam directly, or by means of an intermediate energy conversion, into an electrical signal. The signal thus obtained is fed into a video amplifier and displayed on a television picture tube. Electronic intensifying systems cannot deliver any other form of presentation but a televised image.

Two systems in this group are to be mentioned: (a) image Orthicon pick-up from a standard fluorescent screen; and (b) direct pick-up with an x-ray sensitive Vidicon.

The image Orthicon pick-up is accompanied by the inherent electronic complexity of the system, while the photoconductor used in the x-ray sensitive Vidicon possesses decay properties which require at present the use of high energy, pulsed x-rays at low average intensity levels. Besides the inconvenience of using a rather complex pulsed x-ray system, the increased x-ray scattering due to the use of high energy x-rays together with the increased quantum noise due to low intensity operation decreases the contrast detail reproducibility of this device, a result which is particularly undesirable for medical application.

2. SOLID STATE SYSTEMS

Two devices ought to be mentioned here: (a) opto-electronic mosaic ("image converting panel"); and (b) field enhanced photoluminescence.

Each information point of the opto-electronic mosaic consists of a photoconductor and an electroluminescent element in series. When the impedance of the photoconductor is changed by impinging light or x-rays, the potential drop across the electroluminescent element increases, leading to light emission. The low speed of response and the structure of the panel seem to present difficulties in the practical application of such devices.

Field enhanced, x-ray induced photoluminescence is shown by certain phosphors, such as CdS:Mn. These materials display an enhancement of x-ray induced fluorescence when an AC-field is applied simultaneously with the x-ray excitation. As no exact brightness values relative to the brightness of a standard fluorescent screen, such as Patterson CB-2, are available, the merits of this method cannot be discussed here.

* Linden[4] has also given a summarized description of x-ray image intensifying systems.

† These three systems postulate an x-ray beam flooding the area of scrutiny.

3. VACUUM TUBE SYSTEMS

The systems forming this group may be classified as follows: (a) direct conversion from x-rays to electrons *in vacuo;* (b) conversion from x-rays to visible light taking place *outside* of the vacuum image intensifier; and (c) conversion from x-rays to visible light taking place *inside* the vacuum intensifier.

A direct conversion from x-rays to electrons has been described by Huang[3] and applied to a novel x-ray microscope. The system uses as its x-ray receiving surface a metal foil. The impinging x-ray quanta release Compton-electrons which are multiplied by a back surface secondary electron emitting layer. This composite surface is inserted in an immersion objective of an electrostatic electron microscope. As the Compton-electron yield is rather low, this system is presently limited with respect to both the brightness gain and the contrast-detail reproducibility which may be obtained.

Another system utilizes *conversion from x-rays to visible light outside the vacuum tube.* The x-ray quanta are converted into light quanta by a standard fluorescent screen. This primary x-ray image is minified and projected by a highly efficient Schmidt optical system onto the semitransparent photocathode of a vacuum tube image intensifier with unity magnification. The "quantum sink" may be shifted, in this system, from the fluorescent screen to the coupling light optical system and is then deeper, thus limiting the system as to both resolution and contrast reproduction.

Systems utilizing *conversion from x-ray to visible light inside a vacuum tube intensifier* are commonly known as "x-ray image intensifiers."[1] X-rays penetrate through a window into the vacuum space of the tube and are converted into light quanta by a fluorescent screen. A semitransparent photocathode, in physical contact with the phosphor screen, converts the light quanta into photoelectrons without loss in resolution. An electron optical system accelerates and focuses the electrons onto the viewing screen where they are reconverted into light quanta. The brightness distribution on the viewing screen represents an exact replica of the intensity distribution in the x-ray beam.

X-ray image intensifying tubes of this type seem to yield presently the highest light gain combined with the best contrast-detail reproducibility. However, tubes of this type have had a rather small pickup screen diameter (five inches or less) until recently.

LARGE DIAMETER IMAGE INTENSIFIER TUBE

The development of x-ray image intensifiers with a large pickup screen diameter and high light gain and resolution presented formidable obstacles of a technologic nature. As tubes complying with the requirements of large pickup, high brightness gain, high resolution, and good contrast-detail reproducibility can be used universally in radiology (specific application, cardiology), cinefluoroscopy, radioscopy and television fluoroscopy, as well as in industrial roentgenology, an effort will be undertaken to describe in detail both the design and operation of such a tube having a useful pickup screen diameter of $8\frac{1}{2}$ inches.

GENERAL DESCRIPTION

The x-ray image intensifier discussed here consists of a hard glass envelope, the two halves of which are joined together by heliarc Kovar flanges (Fig. 1 and 2). A relatively thin-walled spherical dome forms the x-ray window and houses the composite pickup screen on a separate support $8\frac{1}{2}$ inches in diameter.* The dome also carries the cathode contacts.

The cylindrical portion of the envelope is covered on the inside with a conductive coating which serves as a focus electrode and is electrically connected to the Kovar flange. The shoulder region of the tube envelope carries on the inside a semicon-

* The merit of directly depositing the composite pickup screen onto the spherical x-ray window will be discussed later.

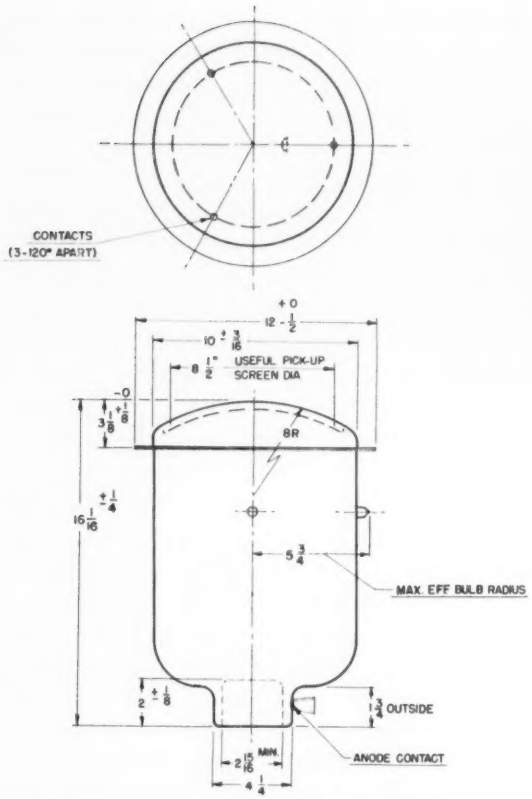

Fig. 1. Dimensional view of the large diameter x-ray image intensifier tube.

ductive coating called "high voltage coating."

The re-entrant seal contains a bullet-shaped metal anode enclosing the aluminized viewing screen. The high voltage contact is located in this region.

The outside glass diameter of the envelope is 10 inches, the over-all length of the tube is 16 1/16 inches. The re-entrant seal has an inside diameter of 2 15/16 inches and a depth of 2 1/8 inches; thus, the viewing screen is easily accessible to a light optical system. The weight of the tube is approximately 7 pounds. The geometric dimensions and the weight indicate that the image intensifier tube can be incorporated conveniently in standard x-ray installations.

The light gain of an x-ray image intensifier is defined as the ratio of the brightness on the viewing screen of the device to the brightness of a standard fluorescent screen,

Fig. 2. Photograph of the x-ray image intensifier tube.

both excited by identical x-rays. The brightness gain of the intensifier is due to both the geometric minification employed and an actual flux gain. A minimum brightness gain of 1000 is obtained with the tube described here.

After this general description, the tube components and some of the techniques applied in producing this device will be discussed in detail. Finally, examples of the performance of this device will be given.

Glass Envelope

As mentioned above, the glass envelope consists of two halves: the x-ray transparent dome and the anode half. The spherical dome is made of hard glass with a relatively high x-ray transparency, while the anode half consists of hard glass with appreciable x-ray attenuation, thus reducing the thickness of the required outside lead shielding. The viewing window in the re-entrant seal consists of optically clear glass.

Design of the Glass Dome and Location of the Pickup Screen. The tube is designed in such a manner that the pickup screen support touches the glass dome from the inside along its entire perimeter. The influence of this design on the viewable size of an object outside the tube can be appreciated if one considers a flat phantom or object to be x-rayed, positioned in such a

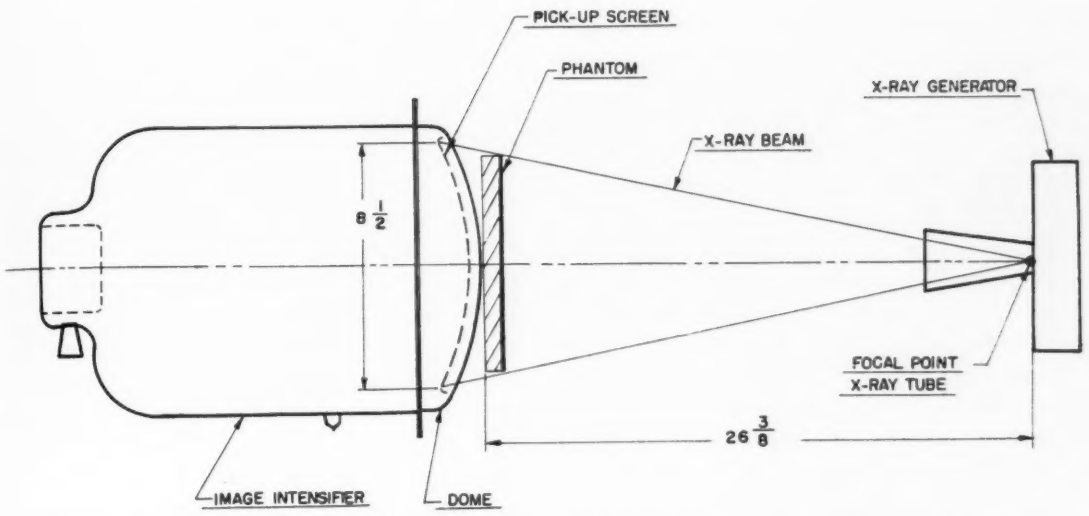

FIG. 3. Dimensional line drawing of an x-ray installation, using an x-ray image intensifier tube.

way that it touches the glass dome of certain curvature from the outside (Fig. 3). It can be seen immediately that the geometric magnification to which the shadow image of the phantom is subjected depends only on the axial spacing between the edge of the pickup screen and the center of the glass dome. This spacing, in turn, is fixed by the radius of curvature of the dome if the perimeter of the pickup screen touches the inside of the glass dome.

Applying the pickup screen directly to the glass dome of maintained curvature does not influence the viewable phantom size if an independent pickup screen support touches the glass dome as described above, as the geometric magnification is again determined by the curvature of the dome. Generally, the radius of curvature of the pickup screen is preferably made larger than the radius of curvature of the dome, for electron-optical reasons to be given later. Making the dome also of the smaller curvature would reduce somewhat the geometric magnification; however, the increase in glass thickness, required to maintain implosion safety, would increase the x-ray attenuation in the dome appreciably and thus result in a reduction of brightness gain. Furthermore, severe linearity distortions may result.

We may assume that the phantom to be observed through the image intensifier is two-dimensionally flat. As the pickup screen is always curved, the projection of the flat phantom onto the spherical pickup screen will lead to pincushion and linearity distortions. For a given x-ray beam divergence, these distortions depend solely on the curvature of the pickup screen.

A linearity distortion can be expressed by:

$$d_2'/d_1' \gtrless d_2/d_1 \tag{2}$$

where

d_1, d_2 = radial spacing from the center of the flat phantom,
d_1', d_2' = the same spacings projected onto the pickup screen.

If d_1 and d_2 are projected by a divergent x-ray beam onto a flat receiving surface (Fig. 4), we can write

$$\left.\begin{aligned} d_1' &= d_1(a+x)/a \\ d_2' &= d_2(a+x)/a \\ d_2'/d_1' &= d_2/d_1 \end{aligned}\right\} \tag{3}$$

If the projection occurs onto a spherical surface (Fig. 4), x in the above equation has to be substituted by x_1 and x_2 with $x_2 > x_1$ for a convex surface, thus indicating a linearity distortion. It follows now:

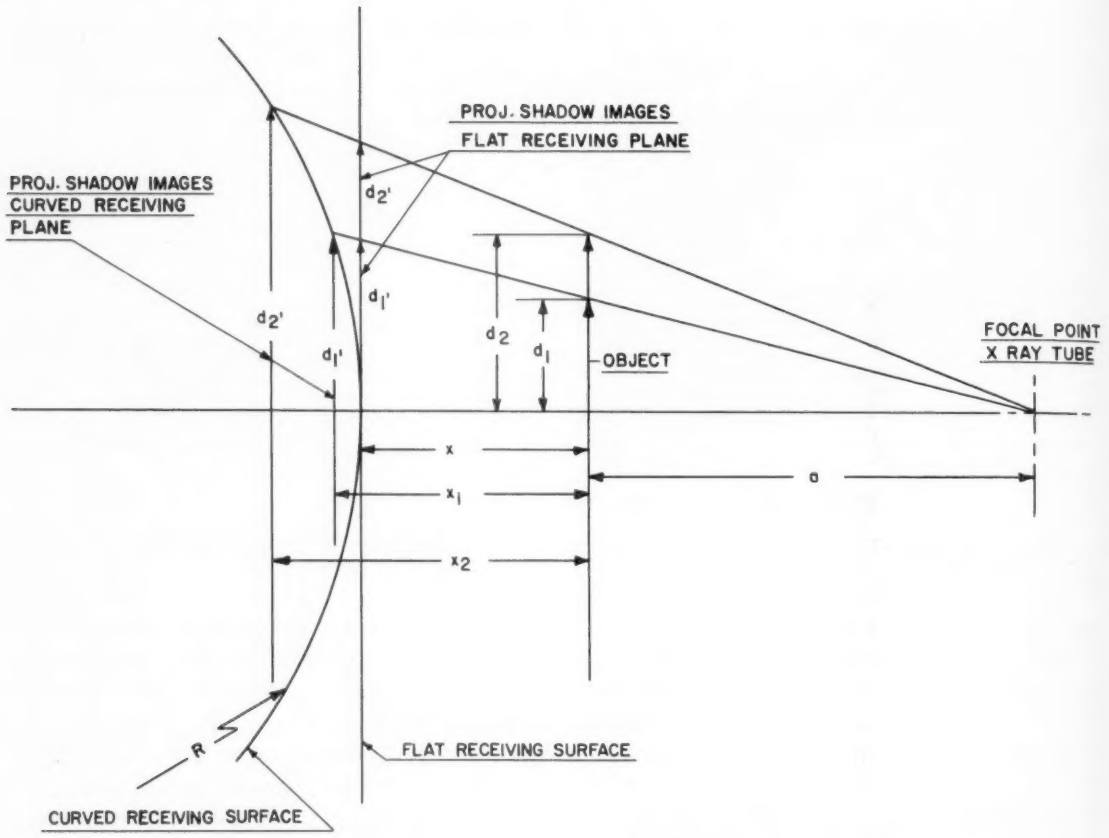

FIG. 4. Projection of a flat phantom onto a flat and curved receiving surface.

$$\left.\begin{aligned} &d_2'/d_1' = (d_2/d_1)\left[(a + x_2)/(a + x_1)\right] \\ &(a + x_1)/(a + x_2) < 1 \\ &d_2'/d_1' > d_2/d_1 \end{aligned}\right\} \quad (4)$$

An expression for x_i may be obtained from Figure 4, using elementary geometry:

$$x_1 = x + R - \sqrt{R^2 - d_1'^2} \quad (5)$$

Equation 5 indicates the increase of linearity distortions with increasing curvatures showing that a flat cathode leads to the least distortion, as expected. Thus, without loss in viewable phantom size, the utilization of a separate screen support minimizes linearity distortions at maintained x-ray transmission of the window.

A spherical window of constant thickness penetrated by a divergent x-ray beam shows increasing x-ray attenuation with increasing radial distance from the center of the window, as marginal rays in the x-ray beam do not penetrate the window perpendicularly, but under an ever increasing angle.

We see in Figure 5 that the effective thickness of the dome as a function of the geometric dimensions of the system considered here is described by:

$$d_r = d/\cos\left\{\text{arc } tg\left[\frac{r}{e + R(1 - \sqrt{1 - (r/R)^2})}\right] + \text{arc sin } (r/R)\right\} \quad (6)$$

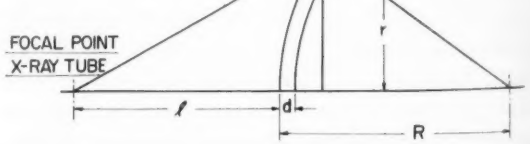

FIG. 5. Geometry used for the derivation of equation 6.

TABLE I

$R=8''$ $d=0.080''$ $l=24''$ $r_{MAX}=5''$

r (inch)	d_r (inch)
0	0.080
1	0.081
2	0.087
3	0.092
4	0.103

The meaning of the symbols used can be seen in Figure 5. A numeric example is given in Table I.

The resulting transmission change depends on the first derivative of the exponential transmission equation for the thickness values under consideration and thus on the mass absorption coefficient of the window material.

The radially increasing attenuation may be compensated by decreasing the window thickness as the radial spacing from the center increases. The thickness of the window as a function of the radial spacing is expressed as follows (with $d \equiv d_{r=0}$):

$$d_r = d \cos \left\{ \text{arc } tg \left[\frac{r}{e + R(1 - \sqrt{1 - (r/R)^2})} \right] + \text{arc cos } \sqrt{1 - (r/R)^2} \right\} \sqrt{1 - (r/R)^2} \quad (7)$$

The radial transmission change of the glass dome is less than 2 per cent considering the glass thickness tolerances and the radial attenuation increase for a typical geometry of medical x-ray installations.

Anode Half. The anode half, consisting of rather low x-ray transparent hard glass, carries the viewing window in a large diameter re-entrant seal. The viewing window is made of optically clear hard glass to permit a faultless pickup of the reproduced image by a light optical system. As mentioned before, the diameter of the re-entrant seal is sufficiently large to make possible the insertion of the lens element of the optical system.

PICKUP SCREEN

Geometric Considerations. The composite pickup screen is supported by a spherical aluminum disk. The x-ray attenuation of the support aluminum is negligible and it may be assumed that practically all x-rays penetrating the dome impinge onto the x-ray sensitive phosphor layer, where they are converted into "blue" light quanta.

If the phosphor coating is irradiated by a divergent x-ray beam, the effective thickness of a uniform coating is greater in the peripheral area than in the center area. This effect leads to a slight brightness increase, as the energy conversion of an x-ray phosphor screen increases with increasing thickness till saturation is obtained. However, inherent "blurring" (x-ray scattering) increases also with increasing thickness. On the other hand, the peripheral resolution is generally somewhat lower than the central resolution (due to the image plane curvature, to be discussed later), if a uniform thickness coating is employed. It has been found that adequate compensation may be achieved by making the center thickness somewhat greater than the peripheral thickness. This correction determines the curvature of the pickup screen surface and lies in the order of several mils.

The curvature of the pickup screen surface is an important electron optical parameter. The curvature $1/R_S$ of the surface can be determined from the curvature of the support $1/R$, the diameter of the support disk $2r$, and the thickness difference Δt, by the following relation, given here without proof:

$$R_S = 0.5 \left[\frac{r^2}{(R - \Delta t) - \sqrt{R^2 - r^2}} + (R + \Delta t) - \sqrt{R^2 - r^2} \right] \quad (8)$$

If we assume $\Delta t \leq 0.005$ inches, it can be seen that $R_S \leq 1.01R$ for a wide range of possible values of R. Thus, for electron optical purposes, it is permissible to utilize the value of R instead of R_S. Equation 8 shows also that small, localized variations of R_S do not appreciably influence the electron-optical properties of the system.

Selection of Phosphor and Coating Thickness. The applied phosphor emits essen-

tially in the blue band, as the SbCs photosurface used in the tube possesses the highest quantum efficiency for blue light. In addition, phosphors emitting in the blue band, under x-ray bombardment, yield a high quantum efficiency.

The particle size of the phosphor is such that the pickup screen resolution is limited by x-ray scattering rather than by the statistical distribution of the grain of the light emitting particles.

The persistence of the phosphor is medium.* The decay after DC x-ray exposure of longer than 10 seconds at intensity levels commonly used in fluoroscopy and cineroentgenography is fast enough to permit both the imaging of any moving process within the human body and mechanical scanning with the image intensifier tube during operation.

The thickness of the screen consisting of phosphor embedded in silicon resin has been selected in such a way that the response to x-rays is "linear," between 75 and at least 100 kv. peak accelerating potential of the x-ray tube (Fig. 6). An approximately 20 per cent lower gain results for operation between 200 and 250 kv. peak.

However, the saturation thickness has not been reached for any operational x-ray wavelength. In other words, some screen brightness has been sacrificed to minimize blurring.

Phosphor Surface and Barrier Layer. The semitransparent photosurface, applied directly on top of the phosphor-resin layer, requires the phosphor surface to be as smooth as possible, as a microscopically rough surface decreases the sensitivity and increases the resistance of the photo-emissive layer.

If electrons are emitted from a surface element dF of the photo-emissive layer, this surface element could assume a more positive potential than the surrounding area if connected to the cathode contact through a high resistance. This effect would alter the potential gradient in front of dF and would lead to values of gamma of the device smaller than one, if the potential gradient drops below a limiting value (space charge limited emission of the photosurface). In addition, the speed of the device might suffer as the charging time of dF increases considerably.

A transparent, very thin resin coating is cast over the resin-phosphor layer to achieve the required microscopic smoothness of the surface. The gloss of a surface prepared in this manner has been determined to be only 2–3 per cent lower than the gloss of a polished glass surface.

Elements of the first group of the periodic table, such as Cs and Na, act as negative catalysts for the silicon resin in the pickup screen at elevated temperatures.

The phosphor surface has, therefore, to

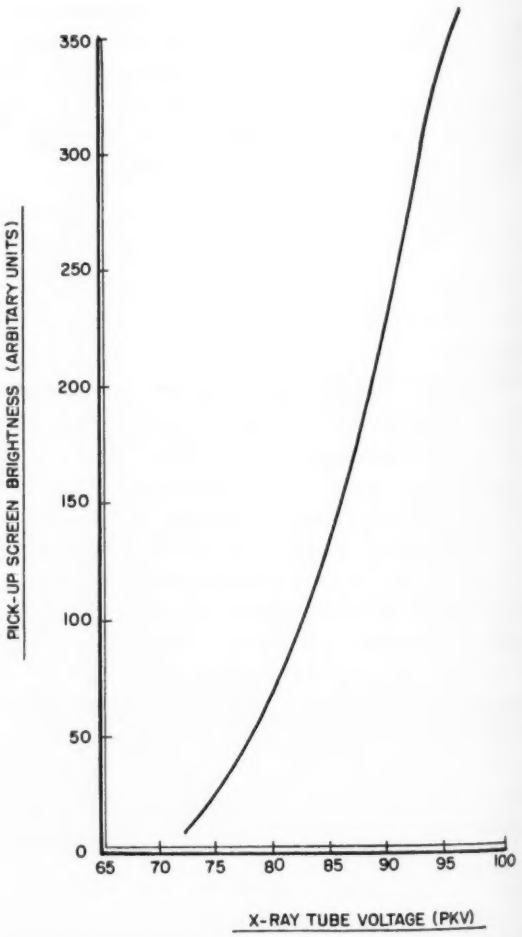

Fig. 6. Brightness of the pickup screen as function of the x-ray wavelength (accelerating voltage).

* Generally, the persistence of x-ray phosphors increases with increasing exposure time for short exposures.[8]

be sealed off by a transparent barrier layer in order to avoid the decomposition of the silicon resin in the presence of Cs at the temperature required for processing the photosurface.

Aluminum oxide is used as the barrier layer material. It is known that Al_2O_3 exists in two forms: the tightly packed and the porous versions. The porous version, which is not self-sealing against oxygen, is not sealing against Cs either. A tightly packed Al_2O_3 layer with excellent properties as a barrier layer against Cs may be readily obtained by heating a thin evaporated aluminum layer in dry air.

VIEWING SCREEN

The cathodoluminescent silver activated ZnS phosphor is settled on a substrate of optically clear glass. The phosphor used has an intrinsic energy efficiency of somewhat higher than 20 per cent at 30 kv. accelerating potential for the bombarding electrons. The relative energy distribution of the light, emitted by this phosphor under electron bombardment, is shown in Figure 7, curve a (solid line). Curve b (dotted line) of the same figure shows the eye response curve for comparison. It can be seen that the light emitted by the viewing screen phosphor matches favorably the sensitivity of the human eye.

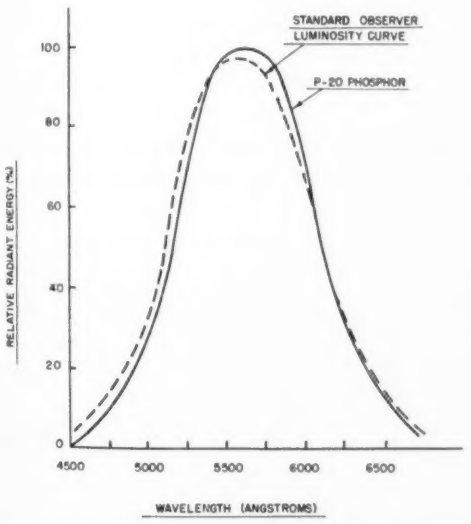

Fig. 7. Relative radiant energy of the viewing screen phosphor and the eye-response curve.

The yellow-green ZnS phosphor may also be matched favorably with proper photographic material such as Tri-X. Proper matching is most successfully obtained if the brightness of the viewing screen is relatively low, namely, 1 to 10 FL. For higher brightness values, 50 FL and more, the maximum in the relative radiant energy distribution shifts slightly towards longer wavelengths and the emitted light becomes subjectively more yellow. This relatively high brightness range is, however, hardly of any importance for image intensifier fluoroscopy and roentgenoscopy.

The resolution obtainable on a settled phosphor screen is ultimately determined by the size of the phosphor particles or the size of the particle conglomerates. The most probable particle size of the bulk phosphor used is 5 μ. This value is reduced by elutriation to approximately 2 μ. Experience has shown that a minimum resolution of 1,000 television lines per inch (500 line pairs per inch—500 optical lines per inch) can be realized readily with such a particle size.

The viewing screen is aluminized to increase the light output, to avoid local charging and to protect the ZnS phosphor against attack by the Cs vapor which is present during processing of the photocathode.*

PHOTOCATHODE

An SbCs photocathode is used. The spectral sensitivity of the semitransparent photosurface matches favorably the spectral emissivity of the blue pickup phosphor used. Further, the quantum efficiency of this photosurface is higher than the efficiency of most other surfaces with the exception of the multi-alkali surface. As the SbCs surface is more easily controlled in mass production than the multi-alkali surface, an SbCs photocathode has been selected. Such a photocathode consists of a thin, amorphous antimony base layer which, reacting with Cs vapors at the processing temperature of 100–170°C. is converted to a layer of the intermetallic

* It is known that most sulfide phosphors are inactivated by the influence of Cs vapors. Silicate phosphors do not display this effect.

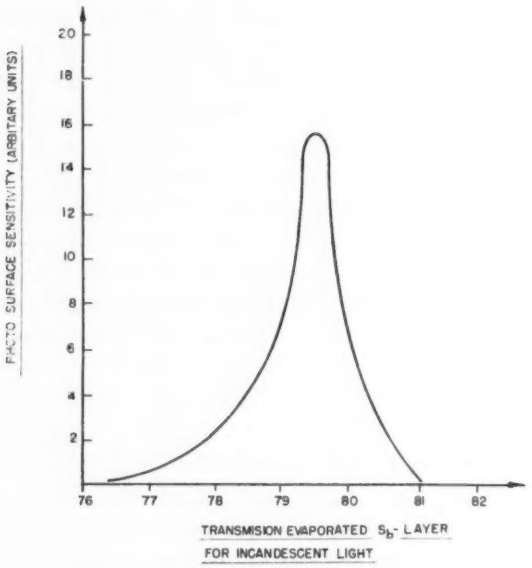

FIG. 8. Thickness of the Sb base layer and photosurface sensitivity.

compound Cs_3Sb. Finally, free Cs molecules, embedded in this layer, are permitted to react with free oxygen brought into the tube to form the final photosurface.

In semitransparent photocathodes, electromagnetic radiation impinges onto the photosurface from one side and photoelectrons are emitted from the opposite side. It is known that photoelectron emission is co-determined by the balance between absorption of light quanta and the depth of photoelectron generation. Thus, the thickness of the photoemissive layer is important. The influence of the thickness of the Sb base layer on the sensitivity of the photosurface used in the intensifier is shown in Figure 8.

ELECTRON OPTICS

Point Symmetric System. The electron-optical system used in the x-ray image intensifier consists of a spherical cathode, spherical pierced anode, and cylindrical focusing electrode. A simpler system, showing imaging properties similar to the system applied in practice, will be discussed first.

Let us consider an electron optical system consisting of two concentric, spherical electrodes: the outer larger sphere is the cathode and the inner smaller sphere is pierced and forms the anode (Fig. 9). The parameters of such a system governing its performance are as follows: with R_C as the cathode radius and R_A as the anode radius, $n = R_C/R_A$; with D_A as the diameter of the aperture in the anode sphere, T_A as the thickness of the anode aperture, and d_{AV} as the distance from the outside of the anode sphere to the image plane, $k = D_A/R_A$. Note that the anode voltage is not included in these parameters. The equations governing the performance of such a system have been derived by Schagen, Bruining and Francken[5] and shall be given without proof. The following assumptions are made: (a) that the image is gaussian, (b) that both cathode and anode are complete spheres, and (c) the anode aperture lens is subjected to the usual assumptions validifying the application of the Davisson-Calbick formula.

Under these assumptions, an object on the cathode is imaged onto a spherical image plane (concave as seen in the direction of electron propagation) whereby the image distance (axial spacing between anode aperture and image plane) is given by:

$$d_{AV} = R_A\left[\frac{1}{n}\cdot 2(n-1) - (n-1)/(n-2) - k/\pi\right] \Big/ 4\frac{n-1}{n-2}\left(\frac{n-1}{n} - \frac{k}{2\pi}\right) \quad (9a)$$

Assuming a very small anode aperture diameter, Equation 9a simplifies to ($k/2\pi \ll 1$):

$$d_{AV} = R_A \cdot 4(n-1)/(n-4) \quad (9b)$$

The resulting image might be either magnified or demagnified, depending on the selection of both the cathode and anode radius.

The curvature of the spherical image plane is $1/d_{AV}$. As the viewing screen in a practical tube is flat (to minimize distortions by image pickup with a light optical system), resolution loss in the peripheral area results, combined with pincushion

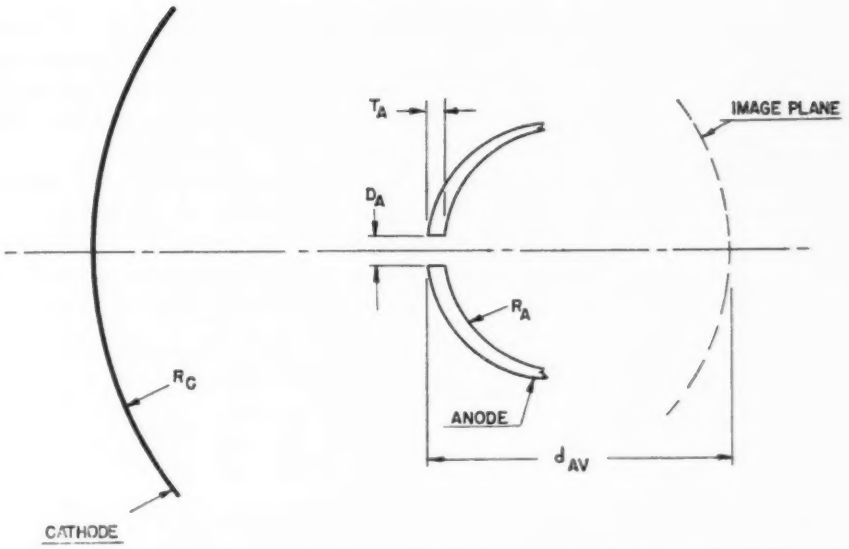

FIG. 9. Point symmetric electron optical system with pierced anode.

distortion. These distortions decrease with d_{AV} increasing.

An increase of the image distance can obviously be obtained by increasing the strength of the (negative) aperture lens (pierced anode sphere). The strength of this lens is increased by increasing T_A, the thickness of the material forming the anode aperture. However, this correction does not change d_{AV} as function of the radial distance of a peripheral object point. Such a correction is, however, required to obtain a nearly complete flattening of the image plane. For this reason, the anode aperture lens is discussed in more detail in the following paragraphs.

*Anode Aperture Lens.** The equations given in the above section treat the anode aperture lens under the usual assumptions, namely: (a) restriction to paraxial rays; (b) thin lens approximation (this means that the influence of the potential in the center of the anode aperture extends to both sides of the aperture, a distance appreciably smaller than the aperture radius); and (c) normal ray incidence (zero angle between the incident ray and the axis of the lens).

* Mr. I. Csorba, of the Rauland Corporation, assisted in obtaining the results discussed under this heading.

The change in strength of the aperture lens with increasing radial spacing r can be discussed qualitatively by adapting the analytical expression for the axial potential $V_0(z)$ in a system consisting of an aperture enclosed by two parallel planes to the anode aperture considered here:[6]

$$V_0(z) = \frac{V_A}{d_{1,2}}\left[\frac{2R}{\pi}\left(\frac{z}{r}\operatorname{arc\,tg}\frac{R}{z} - 1\right) + \frac{z}{2} - |z| + d_{1,2}\right] \quad (10)$$

where r = radial coordinate, z = axial coordinate, $d_{1,2} = R_C - R_A$, and $R = D_A/2$. The potential in the paraxial and (in approximation) marginal space can be obtained by applying the integral solution of the La-Place equation in series development:

$$V(r,z) = V_0(z) - \frac{V_0^{II}(z)r^2}{2^2} + \frac{V_0^{IV}(z)r^4}{2^2\cdot 4^2} \pm \quad (11)$$

For evaluation of the above equation, the second and forth derivatives of the axial potential are given below:

$$V_0^{II}(z) = -\frac{2V_A}{d_{1,2}}\left[\frac{R^3}{(z^2+R^2)}\right] \quad (12a)$$

$$V_0^{IV}(z) = -\frac{8V_A}{\pi d_{1,2}}\left[\frac{5z^2 - R^2}{(z^2 + R^2)^3}\right] \quad (12b)$$

The field strength on both sides of the anode aperture with the origin of a cylindrical coordinate system placed in the center of the aperture follows (with positive values of z in the direction of electron propagation):

$z > 0$:

$$E_{z,2} = \frac{V_A}{\pi d_{1,2}}\left[\text{arc tg}\frac{R}{z} - \frac{zR}{z^2 + R^2}\right] \quad (13)$$

$z < 0$:

$$E_{z,1} = \frac{V_A}{\pi d_{1,2}}\left[\text{arc tg}\frac{R}{z} + \pi - \frac{zR}{z^2 + R^2}\right] \quad (14)$$

and we obtain:

$$E_{z,2} - E_{z,1} = -\frac{V_A}{d_{1,2}}\left[1 + \frac{6z}{\pi r} + \frac{z}{2\pi R^2}\right] \equiv A \quad (15)$$

If $r \gg z$, the axial field strength difference is obtained with:

$$E_{z,2} - E_{z,1} = -\frac{V_A}{d_{1,2}}\left[1 + \frac{2z}{\pi R}\right] \equiv B \quad (16)$$

The ratio A/B gives a correction for the focal length as a function of radial spacing:

$$A/B = \left[1 + \frac{6z}{\pi R} + \frac{z}{2\pi R^2}\right] \Big/ \left[1 + \frac{2z}{\pi R}\right] \quad (17)$$

Note that the focal length f_R for limiting case in the marginal space is now expressed (with f_0 as the focal length in the paraxial space) by:

$$f_R = (B/A)f_0 \quad \text{with} \quad B/A < 1 \quad (18)$$

It follows that the focal length decreases with increasing radial spacing. The decrease of the focal length becomes more pronounced if the rate of the radial potential increase increases. This means that the increasing strength of the negative lens leads to an increasing image distance with increasing radial spacing. This effect may be utilized in practice by selecting an anode aperture sufficiently small so that the aperture lens is filled entirely by the electron beam.

A further correction for the peripheral defocusing will be considered now on a phenomenologic basis. The above equations assume normal beam incidence in the anode aperture lens. However, in the actual case, the rim rays might show an angle of incidence larger than zero. This is particularly the case if the cathode and anode spheres are not concentrical and if the anode is pushed towards the cathode or:

$$\text{axial spacing cathode to anode} < R_C - R_A \quad (19)$$

It is known that the Davisson-Calbick formula for spherical apertures can be modified for an angle of incidence larger than zero:

$$f_{0,\alpha} = \frac{4\Phi_0}{\Delta E_z}\cos^2\alpha \quad (20)$$

with $f_{0,\alpha}$ as the paraxial focal distance (for $\alpha > 0$) and Φ_0 as the potential in the center of the anode aperture. We may assume as a first approximation that the focal distance f_R for the rim rays is modified in a similar way, thus:

$$f_{R,\alpha} = f_R \cos^2\alpha \quad (21)$$

One can see that the strength of the negative anode aperture lens increases with the increasing angle of incidence of the rim rays. Thus, the image plane for the rim rays with $\alpha > 0$ shows a larger spacing from the anode aperture than the image plane for the zonal rays having approximately normal incidence.

This effect, similar to the effect of changing lens strength with increasing radial spacing and normal incidence, flattens the electron optical image plane as a function of the radial distance of a peripheral object point and facilitates receiving of the obtained real image on a physically flat plane.

The application of both corrections to a practical electron-optical system is discussed in the following paragraphs.

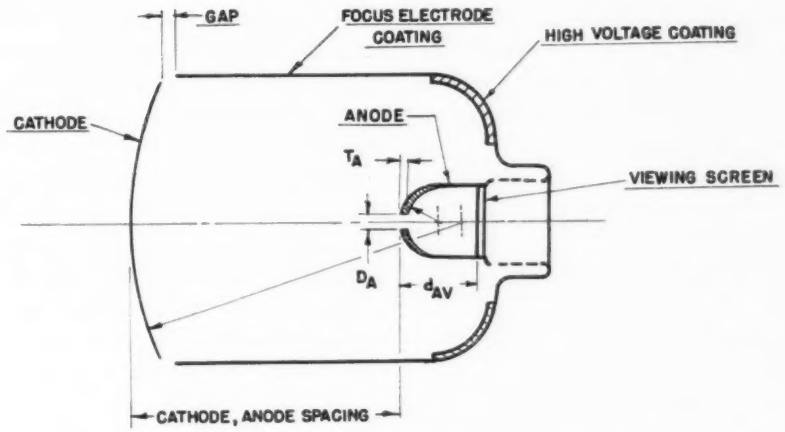

FIG. 10. Pseudo-point symmetric electron optical system.

Pseudo-Point Symmetric System. A strictly point symmetric system, as outlined under *Symmetric System* above, cannot be realized in a practical tube design. Thus, the practical electron-optical system used in the large diameter x-ray image intensifier tube consists of a spherical cathode (C), a spherical pierced anode (A) and a cylindrical focus electrode coating (F) terminated by a semiconductive wall coating (S) (Fig. 10).

The cathode-anode distance d_{ca}, measured axially, is smaller than the difference of the radius of curvature of cathode and anode. The semiconductive coating is terminated on one end by the focus electrode coating and connected electrically to the anode voltage. Thus, the wall potential along the section of the tube envelope covered by the semiconductive coating depends on both the potential difference between the focus electrode and the anode and the resistance properties of the semiconductive coating.

The main purpose of the focus electrode coating is to correct for the finite extension of both the cathode and the anode. Changing the focus electrode voltage (which is approximately equivalent to changing the potential difference between focus electrode coating and cathode) influences both the focal distance of the entire system and the size of the reproduced image. Peripheral defocusing in the image, caused by the spherical curvature of the electron-optical image plane, has been compensated for in the following manner:

(a) The strength of the negative anode aperture lens has been selected as a compromise value by choosing a proper thickness for the material forming the anode aperture (the wall thickness of the material forming the aperture is less than the diameter of the aperture); thus, the radius of curvature of the electron-optical image plane is somewhat increased or the image plane is flatter.

(b) The cathode and anode spheres are not concentric; thus, rim rays emitted from the cathode enter the anode aperture lens in the marginal region under an angle of incidence larger than zero. The image plane flattening effect of this measure has been described in the previous section.

(c) The semiconductive wall coating causes the curvature of the equipotential planes in the neighborhood of the anode aperture to decrease successively in the direction of electron propagation. This effect causes a successive increase in the angle of incidence for the rim rays, the effect of which on the image plane curvature has been mentioned above.

(d) The electron beam fills the entire anode aperture; the image distance for the rim rays is greater than for the paraxial rays, as mentioned above.

Thus, the electron-optical system dis-

cussed here possesses a flatter image plane than an electron-optical system where the focus electrode coating has the sole purpose of compensating for the finite extension of cathode and anode.

FOCUS ELECTRODE COATING AND HIGH VOLTAGE COATING

The focus electrode coating should be nonreflective for the blue light of the pick-up screen which penetrates the semitransparent photocathode, particularly if the coating extends appreciably into the "shoulder region" (Fig. 3), as back reflection of the blue light to the photocathode would result in spurious electron emission reducing the obtainable contrast. Copper, among other materials, shows the property of low reflectivity in the blue band and can be used as a material for such a focus electrode coating. However, an evaporated copper coating suffers generally from a copper oxide interface layer between the glass substrate and the copper. These copper oxides break down at approximately 250°C. at $10^{-4}-10^{-5}$ mm. pressure, thus endangering the cleanliness of the tube and the photosurface sensitivity. In addition, the adherence of an evaporated copper coating to glass is rather poor.

An evaporated aluminum coating, appreciably simpler in production than an evaporated copper coating, can be used if at least the shoulder region of the tube envelope (Fig. 1) is coated with nonreflective material. As the high voltage coating mentioned above is nonreflective in the blue band, the combination of an evaporated aluminum coating on the cylindrical portion of the tube envelope with a proper semiconductive coating in the shoulder region not only approaches the reflection properties of a copper coating alone, but it also renders the tube more practical for mass production.

The semiconductive high voltage coating yields lower values for the local potential gradient along the glass wall between the low potential focus electrode coating and the high potential anode contact, rendering the tubes operable for anode voltages in excess of 45,000 volts. These voltage values can be regarded as being higher than normally encountered in image converter tubes.

The purpose of the high voltage coating may be summarized as follows: (a) establishing the proper wall potential to obtain a flatter image plane; (b) increasing the threshold for high voltage breakdown and local field emission; and (c) reducing the reflectivity for the blue light emitted by the pickup phosphor.

PERFORMANCE OF THE LARGE DIAMETER X-RAY IMAGE INTENSIFIER

STANDARDIZATION OF MEASUREMENTS

As the field of x-ray intensification is a relatively new one, no generally accepted standard for determining performance parameters such as brightness gain, resolution, etc. exists as yet. One of the reasons for this situation may be the inherent difficulty of defining the input energy. Practically all performance parameters depend on the geometry of the test gear, namely, spacing between x-ray generator and image intensifier, divergence of the x-ray beam, etc. Further, the type of x-rays used, namely, wavelengths (anode voltage of the x-ray tube), wave form of the high voltage applied to the x-ray tube (half wave rectified, full wave rectified with ripple, "constant" voltege), etc. is of great importance.

If not mentioned otherwise, all tests were carried out under the conditions and with equipment as described below:

X-Ray Unit. Picker U. S. military unit, type T55-35, 110 volts AC, 60 cycles input, x-ray tube voltage half wave rectified, standard operation 80 kv. peak, 2 ma.

Geometry of the Test Gear. Axial distance x-ray window of image intensifier tube to x-ray focal point, 25″, meshes and phantoms touching the dome of the image intensifier.

Phantoms. Size: 12″×12″ bakelite, lead markers used for 1″ and ½″ divisions orientated in the form of a cross. Resolution: woven meshes, 12″×12″, mounted between

plexiglas sheets, diameter of circular brass wire .012″–.008″. Contrast-detail phantom: plexiglas phantom with holes of constant diameter and varying depths in one direction and holes of constant depth and varying diameter in the other direction (normal to above direction).

Brightness Meter. Spectra Brightness meter, Model UB-1½, Photo Research Corporation.

Telescope. Gaertner Scientific M508, angular magnification 20 times at 140 mm. diameter of object field.

Magnetic Shielding of the Image Intensifier. Mumetal shield, 1/16″ thick, enclosing the image intensifier from the Kovar flange (Fig. 3) to the anode, open on both sides.

In the following sections we shall discuss each one of the performance parameters in detail and describe the measurement techniques.

BRIGHTNESS GAIN

As mentioned above, the brightness gain of the x-ray I.C. depends on both the geometric minification of the tube and the genuine flux gain due to electron acceleration.

As the size of the output image depends somewhat on the focusing voltage, the x-ray I.C. is first adjusted for proper focus voltage at the operational high voltage by using a resolution mesh. Then the resolution mesh is removed and a 20 mm. thick solid pure aluminum phantom is inserted between the x-ray window of the image intensifier and the x-ray tube. The x-ray attenuation of the aluminum phantom is comparable to the x-ray attenuation of the average human chest.

The brightness of the viewing screen is measured at 80 kv. peak, 2 ma., x-rays after an excitation of at least 10 seconds.

Thereafter, the x-ray image intensifier is removed and a Patterson CB-2 screen* is inserted at the location of the intensifier pickup screen. The brightness is again determined under identical x-ray intensity and measurement conditions. Then, the brightness gain is obtained by dividing the brightness on the viewing screen of the x-ray image intensifier by the brightness of the Patterson CB-2 screen. A minimum brightness gain of 1,000 is guaranteed. The most probable brightness gain is around 1,500 and considerably higher values have been obtained.

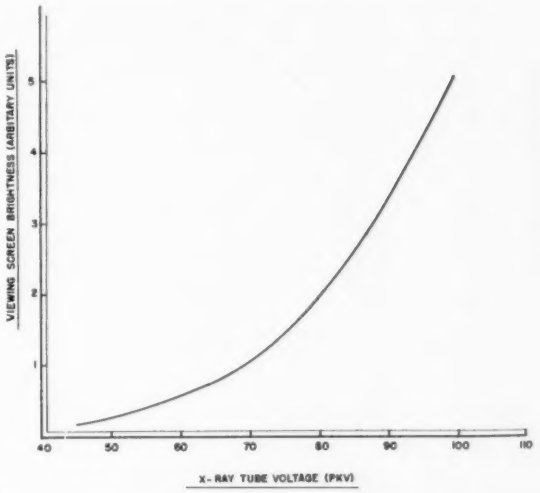

FIG. 11. Brightness of the viewing screen as function of the x-ray tube voltage.

The brightness gain of the tube (or the brightness of the image on the viewing screen) is approximately flat with increasing x-ray hardness (decreasing x-ray wave lengths) between 75 kv. peak and 110 kv. peak as shown in Figure 11. Thus, the tube can be used successfully in the normal x-ray range encountered in medical and also in industrial radiology.

The brightness on the viewing screen depends further on the anode voltage applied to the x-ray image intensifier, as shown in Figure 12. It can be seen that the brightness versus anode voltage curve increases around 30 kv. anode voltage. However, the rate of increase decreases beyond approximately 33 kv. This means that the minimum required thickness of the viewing screen at the operational anode voltage has been selected. A greater thickness of the viewing screen might lead to a resolution loss.

* The Patterson CB-2 fluoroscopic screen has almost the same relative radiant energy distribution as the viewing screen phosphor of the image intensifier.

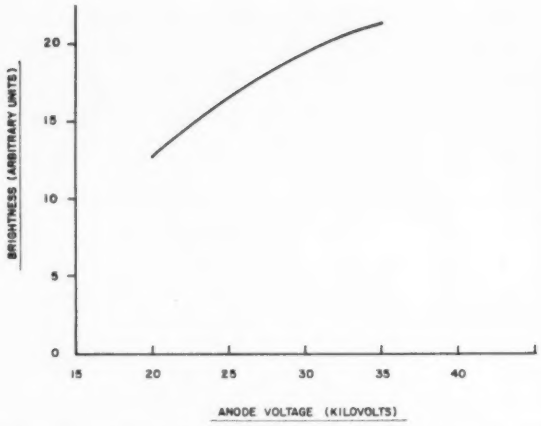

FIG. 12. Brightness of the viewing screen as function of the intensifier anode voltage.

The brightness gain values discussed here have been obtained at a nominal minification of 7.5.

RESOLUTION

By "resolution" is meant the limiting value of the contrast-detail perceptibility curve for contrast values approaching 100 per cent.

The resolution is determined under the conditions described in the section, *Standardization of Measurements*, above, at the operational x-ray brightness level (but with an aperture of 0.3 mm. at the x-ray tube). This means the x-ray tube is adjusted to 80 kv. peak and 2 ma. and the 20 mm. aluminum phantom is used between the resolution mesh and x-ray tube. The resolution mesh is inserted between the x-ray window of the intensifier and the aluminum phantom with as close spacing as possible.

A resolution of 80–100 television lines per inch is achieved on the pickup screen across a central area with a diameter of approximately 85 per cent of the total useful pickup screen diameter. The peripheral resolution is equal or greater than 55 television lines per inch with the focus voltage adjusted for optimum resolution in the central area.

A certain amount of pincushioning, resulting from the projection of the somewhat curved electron-optical image plane onto the flat viewing screen and the flat phantom onto the curved pickup screen, is unavoidable. Figure 13 shows the photograph of wire mesh imaged onto the viewing screen of the intensifier tube, to illustrate pincushion distortion. The photograph has been made under the condition as described above.

PICKUP SCREEN DIAMETER AND IMAGE SIZE

Both the pickup screen diameter and the image size depend somewhat on the focusing voltage. Thus, the pickup screen diameter is determined with the size phantom (see above) and a resolution mesh is inserted as close to the x-ray window of the intensifier tube as possible. Then the image intensifier is adjusted for proper focusing and the lead markers of the size phantom are counted in the reproduced image.

As mentioned above, a slight geometric magnification must be taken into account caused by the divergence of the x-ray beam and the unavoidable physical spacing between the flat size phantom and the edges of the curved pickup screen. Thus, the actual phantom diameter is slightly smaller than its shadow image on the pickup screen. For a typical medical x-ray set-up as described above and the size phantom practically touching the x-ray window of the tube, the geometric magnification value amounts to approximately 1.1.

The usable pickup diameter is $8\frac{1}{2}$ inches. The image diameter can be determined experimentally by a simple measurement (average value 1.15).

SPEED OF RESPONSE

The speed of response is measured with a photomultiplier pickup (S-11 surface, head-on multiplier) and a DC-oscilloscope under the test conditions previously described. The 20 mm. aluminum phantom is inserted between the window of the image intensifier and the x-ray tube, and the x-ray tube is operated at fully rectified high voltage ("constant voltage"). The decay is determined after an x-ray excitation period of at least 10 seconds. The brightness of the output phosphor decreases to 5 per cent of the

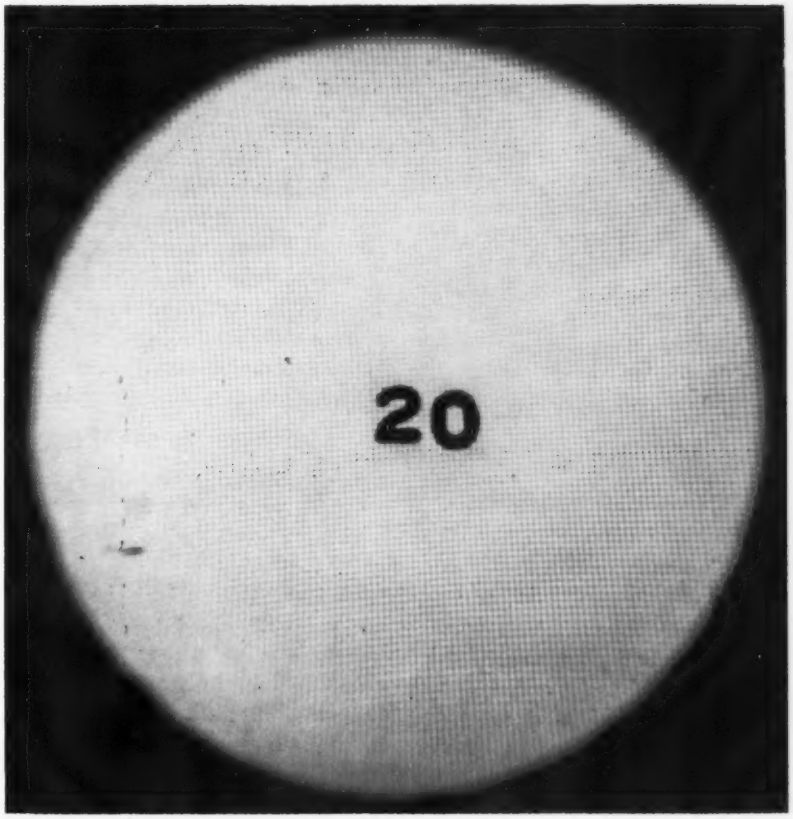

FIG. 13. Photograph of a mesh phantom showing the pincushioning effect in the peripheral area.

original brightness within 0.2 seconds (Fig. 14). This speed of response is sufficiently fast so that no limitation is imposed on the use of this device in medical fluoroscopy (with and without scanning of the subject with the intensifier tube), radioscopy and cinefluoroscopy as well as television fluoroscopy.

As the speed of the pickup phosphor depends on the duration of x-ray excitation, the decay of the image intensifier for 60 sinusoidal half cycles per second x-ray excitation is so fast that the brightness of the output phosphor decreases to practically zero between the half cycles. Thus, the device is very well suited for relatively fast response, pulsed x-ray operation.

CONTRAST-DETAIL PERCEPTIBILITY

As mentioned at the beginning of this paper, contrast and detail perceptibility are connected by the simple relation,

$$C = (B_2 - B_1)/B_1 = k/\sqrt{N} \quad \text{(Equation 1)}.$$

For small values, the contrast C can be expressed by:

$$C = ln\,(B_1/B_2) \qquad (22)$$

It is convenient in using a contrast-detail phantom, as described under *Standardization of Measurements*, to express the contrast C by thickness of the material penetrated by the x-rays. Realizing that the x-ray attenuation follows an exponential law with the attenuation coefficient K in the exponent, we obtain for C:

$$C = K\Delta d \qquad (23)$$

whereby Δd represents the difference of the full material thickness of the phantom and the thickness of material remaining in the holes (or the depth of the holes).

Contrast-detail perceptibility curves have been determined with the phantom in-

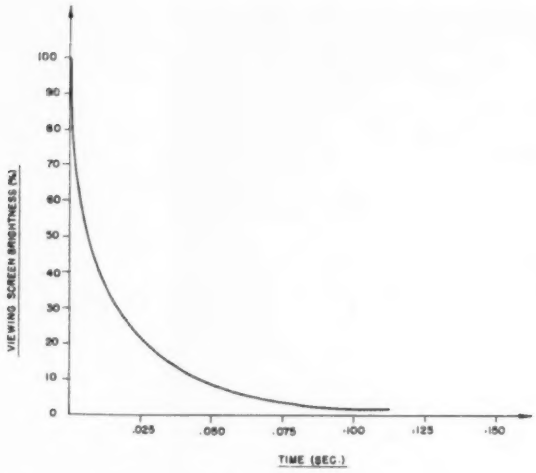

FIG. 14. Decay of the viewing screen brightness.

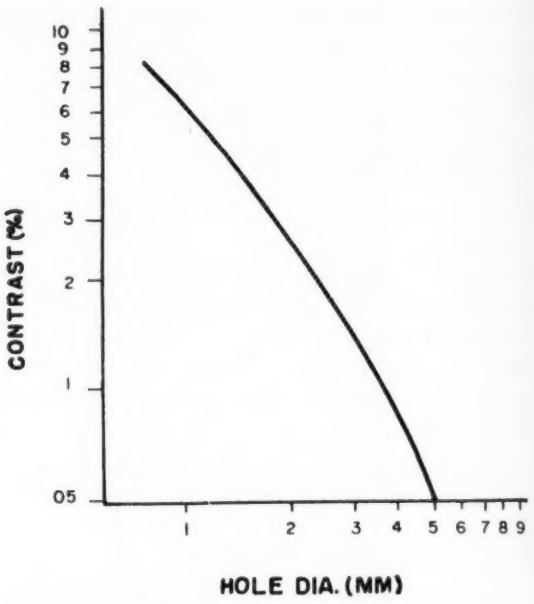

FIG. 15. Contrast-detail perceptibility curve.

serted between the window of the image intensifier and the 20 mm. aluminum phantom under 80 kv. peak, 2 ma., (half-wave rectified) x-ray excitation. The geometric setup was equal to that described under *Standardization of Measurements*. A typical curve is shown in Figure 15.

SUMMARY AND CONCLUSION

X-ray image intensification permits a reduction of the radiation doses in fluoroscopy as well as the application of cinematography and television techniques to medical radiology.

X-ray intensifying systems, namely, electronic, solid state and vacuum tube systems, are surveyed and the conclusion is reached that only vacuum tube systems have been developed to such a technical maturity as to permit successful practical application.

The design of a large size vacuum tube x-ray image intensifier (cathode diameter $8\frac{1}{2}$ inches, minimum brightness gain 1,000) is described. Structural details such as the cross-section profile of the x-ray window, location of the pickup screen and linearity distortions, etc. are discussed.

Further, the imaging by the electrostatic triode system, used in this tube, is analyzed mathematically with special emphasis on the properties of the negative anode aperture lens and the curvature of the image plane of such a system. The concept of a "pseudo-point symmetric system" is outlined together with the function of the "high voltage coating," a new electron-optical element for structure of this type.

Performance data of the large size x-ray image intensifier are listed in detail together with a thorough description of the measurement techniques used.

In conclusion, it can be stated that the x-ray image intensifier tube described here is universally applicable to medical radiology and may also be used to advantage in the field of industrial x-ray techniques.

The Rauland Corporation
4245 North Knox Avenue
Chicago 41, Illinois

The development of a system incorporating a novel component necessitates cooperation between several companies as well as the forming of scientific teams within those companies. Thus, it is hardly possible to give credit here to all those persons who are entitled to it.

Corning Glass Works, Corning, New York, and Kimble Glass Company, Toledo, Ohio, deserve credit for services rendered in the development of the glass envelope of the intensifier tube. The Picker X-ray Corporation, Waite Manufacturing Division, Cleveland, Ohio, developed the x-ray equipment on which the x-

ray image intensifier is used and carried out invaluable work in evaluating the performance of sample tubes. Dr. J. Ball and Mr. E. B. Graves were especially helpful in this respect.

I am greatly indebted to Dr. C. S. Szegho, Director of Research of The Rauland Corporation, for continuous guidance and encouragement in developing the intensifier tube. Mr. A. Schmidt and Mr. H. Jordan assisted substantially in solving many chemical and mechanical problems. Finally, the Glassblowing Shop of The Rauland Corporation, under the supervision of Mr. H. Voelz, deserves credit for developing the first experimental glass envelopes.

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TELEVISION CINEROENTGENOGRAPHY: DOSE AND CONTRAST FACTORS*

By R. STUART MACKAY, Ph.D.
SAN FRANCISCO, CALIFORNIA

THAT a television system can give a large bright multiple image remote from scattered radiation is well known. The use of roentgen rays in conjunction with television to reduce the dose to patient and physician was patented by the Frenchman, A. Dauvillier, in 1915, and the system was demonstrated by him in 1928. Besides the advantage of requiring minimum dark adaptation from the viewers, such systems can provide image brightening over a wide subject field. They can give reasonable contrast at high voltages where some intensifiers are ineffective because of the direct activation of the rear phosphor by the penetrating rays. In cineroentgenography a given image quality can often be produced with less dose by using television techniques, and this aspect will be discussed here.

Much has been written and said about roentgen-ray detectors and, of course, they are the heart of any such system. In the present paper the detector will not be considered, but only how to systematically make the best possible use of the one available. The discussion will hold for any detector that shows storage, *i.e.*, in which the effect of each interacting quantum is added to that of all the previous until a scanning process removes the accumulated information at any one point in a single signal. Commonly used examples of such detectors are the vidicon and the image orthicon, used with or without a preceding image intensifier, upon which is focussed the image of a fluorescent screen, and the roentgen-ray sensitive vidicon, which is a semiconductor device directly sensitive to roentgen rays.

In rendering a roentgenographic image visible, roughly the same number of increments from light to dark are discernible photographically as with television. But with television, emphasis can be concentrated to study one small range in detail. However, a large roentgenogram can contain detail corresponding to a band width in the hundred megacycle range at normal frame rates (Appendix 1) and its grain can be somewhat less troublesome than the noise characteristic of most detectors at low levels. A discussion of film and television methods has been given.[1] Film and electronic detectors can show similar quantum efficiencies. Thus television procedures can be advantageous; but to maximize information transfer and minimize dose, one must also consider the television link and camera. For example, nonlinear circuits can enhance contrast and make detail more noticeable. One can sometimes see more in a television image than by direct viewing.

CONTRAST

Contrast (taken as the percentage change in intensity at a boundary of a given structure) in the original unconverted roentgen-ray image depends not on roentgen-ray intensity but on roentgen-ray wave length distribution. This may be monitored with a scintillation detector and the gray wedge pulse height analyzer shown in Figure 1. Each interacting quantum has its energy recorded. Because of the multichannel action, this unit can give a spectrum from a tube running under normal operating conditions without requiring an exposure time comparable with the tube life. Various machines can thus be adjusted to give comparable outputs. It is also suitable for use under low intensity conditions such as in evaluating beam hardening on traversing a patient (assessing the outcoming spectrum). An example of the result is shown in

* From a paper presented at the Second International Medical Electronics Conference, Paris, France, June, 1959.

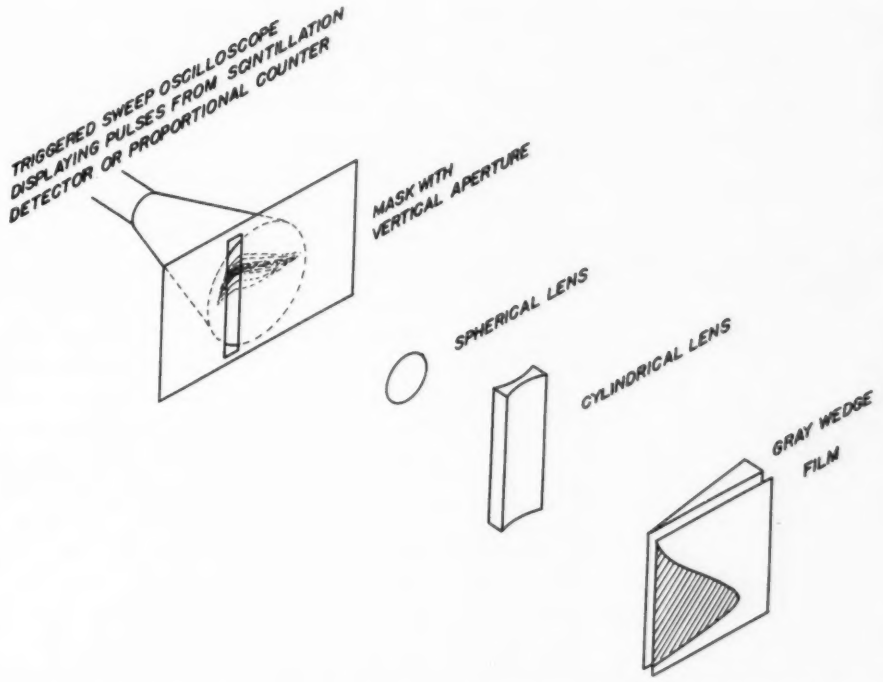

Fig. 1. The peaks of the pulses form a vertical column of bright spots which are spread by the lens system into horizontal lines, one above the other. The film will be blackened, to a given degree, farther to the right at a level where several pulses occur with the same height due to several quanta of one energy entering the detector. The spectral distribution appears directly on the film and curve shape does not depend on the linearity of the film or phosphor. The wedge can be replaced by a triangular diaphragm, or the cylindrical lens can be eliminated by using the expanded or fast delayed sweeps on certain oscilloscopes. Nonuniformities in the phosphor or optical system can be compensated for by placing before the film a mask made by exposing a negative while there is a vertical line on the screen. In general, this seems unnecessary.

Figure 2. Such absorption spectroscopy should allow composition analysis, thus making roentgenography more quantitative, and it should also provide maximum contrast images (Appendix II).

When the television image is photographed, film density need not be a function of roentgen-ray intensity or dose since the television output can be brightened arbitrarily. Structure may be better defined than in direct exposure since with a television detector a given blackening can be due to many absorbed quanta rather than many progeny per interaction. Too many or too few progeny per absorbed quantum are both bad. In one case the film can be black before detail is defined[2] and in the other there is no visible image with reasonable dose. With television the dose demanded can depend only on the detail to be resolved and image detail corresponding to any dose level can be recorded (subject to detector limitations) since the sensitivity of the recording medium need not be considered in choosing the exposure.

Usually, if the over-all response of the television system is such that when output brightness is plotted as a function of input intensity, as in Figure 3, the resulting curve is concave upward, then contrast is enhanced. Subtle details can become more noticeable.[2] The over-all response can readily be changed by a biased-diode electrical network. Even if the circuits are linear, the over-all response will usually be of the above character because many cathode ray tubes give an output that is proportional to approximately the 2.5 power of their input voltage. If photography is used in rendering the roentgen-ray

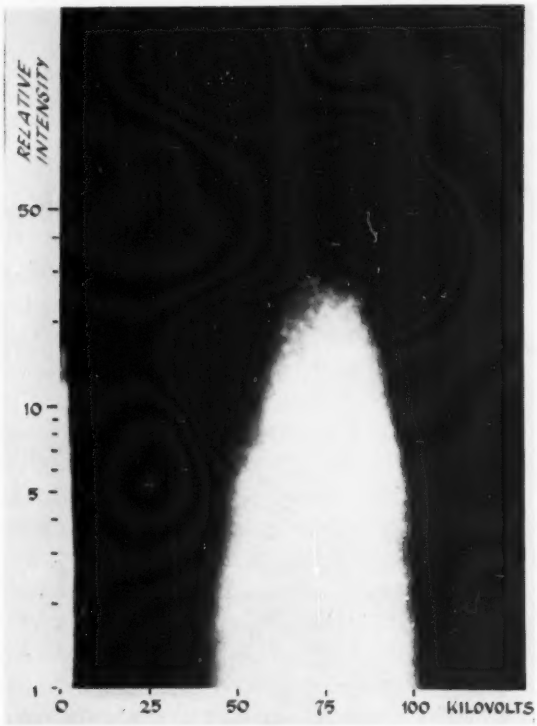

FIG. 2. Energy distribution as presented by scintillation detector and pulse height analyzer. The roentgen-ray source was a tungsten target tube fed by an unfiltered full wave rectifier set at 100 kv. The beam was filtered by 0.5 mm. of aluminum and 7 m. of air. Approximately 4,000 quanta interacted with the detector in less than one half second. Detectors do not show perfect resolution, but in this energy range they are not troubled by Compton interactions or pair production. If more quanta are used to give a smoother curve then it should prove possible to employ an optical computer based on filtering spatial frequencies to correct the observed distribution for imperfect energy resolution.

image visible, then film nonlinearity is also involved. These nonlinearities can be augmented electrically to make saturation transitions more abrupt outside the range of interest.

Precisely, contrast is enhanced if the tangent to the response curve crosses the axis to the right of the origin.[2] In Figure 3 are seen some examples of contrast altering responses. An electrical bias or ambient illumination can lead to a sharply rising characteristic at the origin. A large slope in the region of interest is required to notice subtle detail. To detect a tiny signal when there is a threshold sensitivity requires a high slope near the origin. The simple curve that gives this is concave down. This is the case in radar work[6] and it can sometimes be applicable in radiology. To best use the remainder of the dynamic range, a concave up region might then follow the threshold level. It can be shown that an equivalent criterion for contrast enhancement requires that the slope on a log-log plot be greater than unity (Appendix III).

An undetectable gradient may sometimes be noticed if it is moved or in motion. (For example, one can sense the motion of interference fringes that one cannot see.) This not only suggests another way for studying roentgenograms, but it also indicates that more may be visible in a movie than in a set of stills with the same contrast.

MOVING PICTURES

If one uses a standard sound camera (24 frames per second) to record the image as in standard television practice (30 frames per second, two field per frame interlace), then dose will be 2.5 times that necessary to produce the given image quality and resolution will only be approximately half that potentially present. The former is due to the camera shutter being closed for three fifths of the time, and the latter because successive fields do not appear on the same or on successive movie frames and after projection there is little chance of interlace. Because of storage effects in the detector, dose is not reduced if the roentgen-ray beam is turned off whenever the shutter is closed, but there will then be a 4-to-1 exposure difference across each frame. Interrupting the detector scan is usually preferable to and easier than interrupting the roentgen-ray beam. In order to avoid loss of information or excess dose, one must employ either a shutterless recorder with continuously moving film, or a camera with "instantaneous" film advance. The problem is not that the patient is irradiated while the shutter is closed but rather that

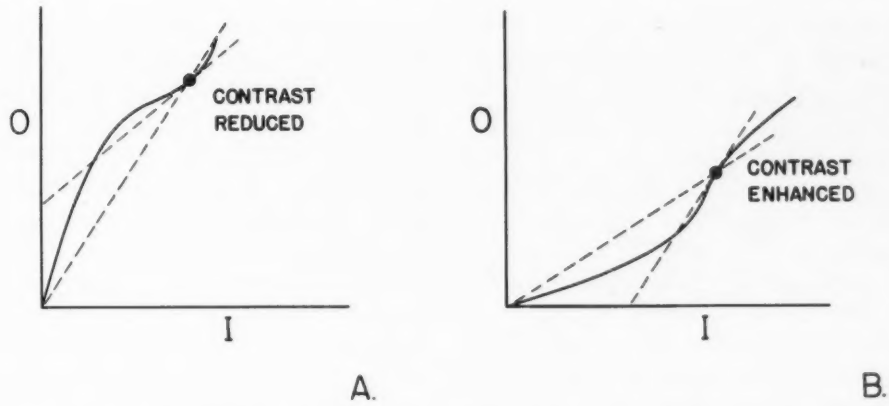

Fig. 3. Examples of response of a television system: visible light directed into eye versus input roentgen-ray intensity from subject. These characteristics are sketched with an inflection point. Though unusual, contrast can be enhanced in a range where the transfer function is concave downward, or decreased when it is concave upward, depending on the slope of the tangent at the point compared with the slope of the line drawn to the origin.

the detector is being scanned and erased at that time. One can consider many cycles of storage and recording in which there is time for a normal film "pull down," but most have some fault, one of the more common being loss of uniformity due to asymmetry in storage when different sections are returned to after different storage times. Mechanically, the continuously moving film camera seems the most durable.

A continuously running film camera photographing a short-persistence phosphor (P 16) on a cathode ray tube with no vertical deflection need lose the effect of no interacting quantum. Camera frame height can be changed by applying attenuated forward or reverse vertical sweeps to the output tube. Frame width can be controlled by camera distance. In principle, two-field-per-frame interlace can be retained if there is a full verticle sweep in full *frame* time on the output tube. A particular phase is not necessary in starting the film since this only requires adjusting the projector gate. However, in the present apparatus a tiny phototube in the camera generates an impulse each time a sprocket hole in the film passes a fixed point. This signal triggers each television frame start for stability and also fixes the starting phase. Feedback from a roller in the film loop can also be used to control the cathode ray line position if there is a tendency for the image to drift. To prevent phosphor burn, the output tube is turned off when the roentgen-ray beam is off, and tube elevation is periodically altered. Sprocket hole feedback is also used to trigger a flash tube to record auxiliary dials (*e.g.*, clocks and pressure gauges) directly on the film. The camera used in the present studies was made in the fashion of some magnetic tape recorders, but presumably one could use a commercial rotating-prism camera after removing the prism.

Because of storage in one's visual system, the dose is relatively independent of the frame rate if each frame need not be suitable for individual study. Any decrease in the viewing relative to the taking rate increases the required dose. If in clinical study one wished to concentrate on a single frame at a time, then the roentgen-ray beam current would have to be turned higher, proportional to frame rate, so that each frame alone would contain an adequately detailed image. In this case dose increases proportional to frame rate and one should take frames at the lowest rate that will record the motion involved. There should be no movement between two frames that is more than, say, one third the finest expected dimension of interest. If

one wishes to stop any blurring, the image can be laid down with a short roentgen-ray pulse once per frame. On the other hand, steady irradiation at a lower rate during the whole frame allows one to learn, through the appearance of blur, of any unsuspected fast component of motion. Stereo pairs can be laid down on successive frames by two adjacent roentgen-ray tubes that are alternately pulsed between frame scans.

To fully use the available band width, the amplifiers must carry a signal at all times. Slowing the camera from 30 frames per second to 24 can be done with feedback controlling the television frame rate as indicated above. If band width limits the image quality (it should not), then appearance will improve. Fifteen frames can be had without feedback by employing a 15 frame film speed and interlaceless raster at 30 frames with a full forward vertical sweep on the output tube while blocking both the detector and output tubes' scanning beams every other frame. Storage time is the same with or without interlace; besides implications for exposure and storage perfection, this means that alternate fields of a frame cannot separately be recorded to form a double speed film of half vertical resolution unless one broadens the detector spot vertically so all stored information is taken in each field. A 24 frame rate is for the recording of sound (time markers, commentary and body sounds) and its reproduction in teaching films shown on unaltered movie projectors. However, changes in frame rate by a factor of two can be had without change in pitch, or loss of intelligibility of accompanying sound, by the use of a periodic-sampling time compressor or expander.[1]

If detector storage is perfect (this does not blur motion as would increased phosphor persistence), then an unfiltered roentgen-ray voltage source will not degrade the image if there is an integral number of electrical cycles (or identical half cycles from a full wave circuit) in one frame time, because all points will "see" the same full cycles of roentgen-ray intensity before being sampled again. Slight banding of the image has been observed due to lack of perfect storage with an RCA 6849 image orthicon.

Across the picture on the viewing monitor appears a thin line that can be moved to cross the region of interest. On an adjacent oscilloscope appears the brightness pattern along this line; when this just fills the graticule, gain and brightness are adjusted so that the subject is optimumly matched to the full range of the film. (An exposure meter does not allow for range or important small structure.) For initial use, a graph of film density versus grid voltage is needed. A block diagram of the circuit is shown in Figure 4 and some observed patterns in Figure 5. With this method one can emphasize a particular structure in a systematic way, or alternatively, be sure of including all structures of interest.

Roentgen-ray intensity is separately set so that the *darkest* region of interest matches a predetermined intensity; structure there will then be statistically adequately defined, as it will be in all brighter regions. If finer detail is expected then this intensity is raised accordingly. To decrease the smallest resolvable distance by n means increasing the dose by n^2 since the number of quanta that formerly went through any unit area must now traverse each area smaller by n on a side.

MAGNETIC TAPE RECORDING

A magnetic video-tape recorder proves to have enough band width (4.5 megacycles) to replace the camera for many purposes if the image quality is always degraded by dose reduction to the minimum acceptable, as it should be. Such a unit records with a resolution of approximately 400 lines in the horizontal direction and 500 in the vertical direction, which is about as good as the information that our detector will supply at low light levels. The tape recorder shares the advantage of the shutterless camera in losing no interacting quantum, and it can be used as an erasable intermediate storage from which interesting material can be

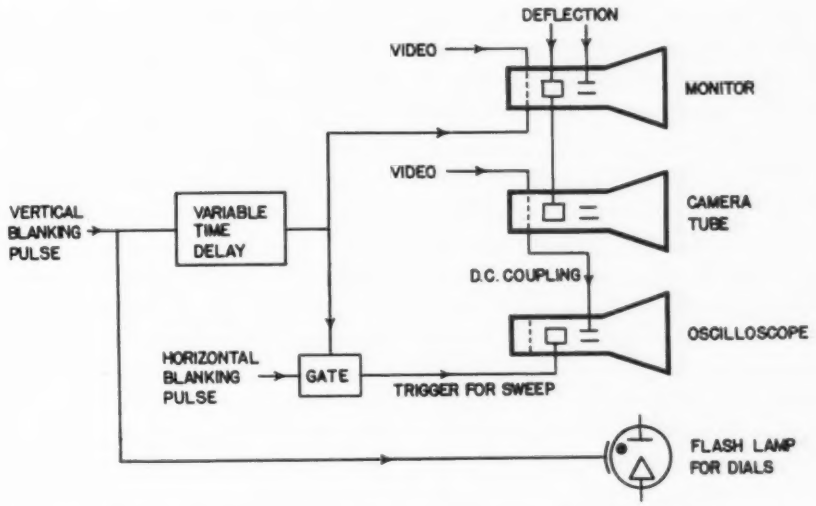

Fig. 4. Scheme of circuit used to systematize exposure control. The delayed sweep control on a Tektronix 545 oscilloscope will supply these functions.

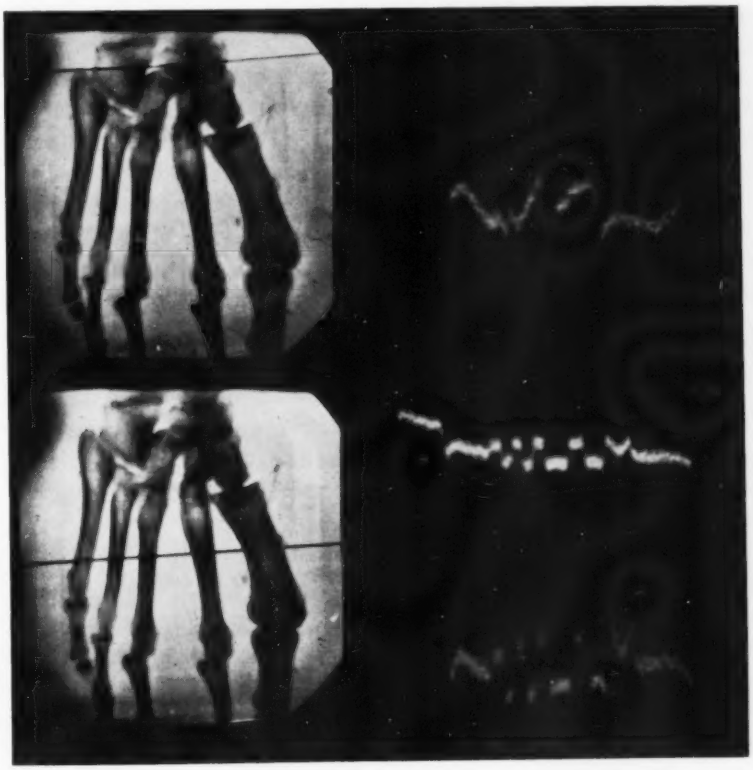

Fig. 5. Monitor displaying some hand bones, and the intensity pattern corresponding to a certain line of the image. When adjustment is such that the pattern falls within the two center lines of the graticule, then that portion of the image will be recorded properly. Portions of the image outside this voltage range will fall in the saturation regions of the film characteristic and will be ignored. The lower example shows two gain and bias settings, increasing darkness being upward.

transferred to film. The recorder gives a record that is immediately available for study, or redoing if some aspect of interest is not captured. Experience may show that in practice the greatest saving in dose will result from taking only as many frames as needed rather than exposing extra "precautionary" footage before releasing the patient.

With an image recorded in this form, image processing[2] can be optimized by varying parameters (*e.g.*, the amount of derivative mixed with an image to emphasize contours) while comparing the modified and unprocessed images on two monitors. One investigation will take two signal levels and from them, introduce color into the image by the Land method[3] to observe the effect on detail perception. (Minimum dose requires either monochromatic roentgen rays or a true color display, which the previous is not because of the mixing of the effect of the various roentgen-ray wave lengths.)

At present the following practical observations can be made in connection with tape recorders. It is extremely convenient that anything seen on the monitor is properly recorded, and the eventual appearance can be modified as desired during playback. Time, labor and extra equipment for film processing are dispensed with. The fast rewind feature in many cases allows almost the same result as the single-frame viewing possible with film, though single fields can be studied by using such a storage tube as the Tonotron. The appearance of the image is relatively satisfying and has proved useful clinically.

NOISE

The effect of a nonlinear system on the signal-to-noise ratio is difficult to predict and must include the signal distribution, the noise distribution and the position, extent and shape of the nonlinearity. However, when fluctuations in a brightness level are all small with respect to the magnitude of that level, as are most signals that would be enhanced, then contrast enhancing nonlinearities will not significantly change the signal-to-noise ratio. Thus after such enhancement, distractions from pattern are the same, but previously unnoticeable things are accessible to the visual system. Large noise pulses will diminish in relative effect after contrast enhancement if they are limited by a saturation nonlinearity while the smaller useful signal is expanded. Similarly, very contrasty structures may become no more important and thus they may be relatively less distracting. But it should be remembered that smooth test objects, such as partial holes in a metal plate, can give rise to overly optimistic views of the utility of such procedures because there are cases where recognition is not limited by contrast.

The signal-to-noise ratio is the same with a continuous or with a pulsed roentgen-ray source for a given dose. It should be noted that there is *not* adequate evidence that the biologic effects of the dose in the two cases is the same.

It is assumed that normal precautions are taken in the use of the detector. Thus, with an image orthicon the scanning beam must be no more intense than required to just discharge the highlights. Wallman has noted that high frequency noise is less disturbing to the recognition of pattern than low frequencies, and that a vidicon concentrates its noise at the higher frequencies while an image orthicon has a more uniform noise spectrum. Limiting the amplifier frequency response to just that required to carry the picture does not seem to help clarity much, probably because of the smaller importance of the fine parts of the noise pattern.

One comment on the size of the detector might be warranted. Increasing the diameter of an image orthicon used with a given speed lens is useful because, though there are no more "lux," there are more "lumens" (*i.e.*, the flux is increased but the illumination is not). Thus the total current will increase since a photocathode is characterized by a certain number of lumens per microampere. Fluctuations will tend to in-

crease with the square root of the current and thus the net advantage is a slowly increasing one as the area is increased.

A synchronous camera motor eases problems of hum, pickup, stray magnetic fields and power supply ripple, mainly because induced nonuniformities then tend to be stationary with respect to the image.

The disturbing scanning line structure in a television image, since it is periodic, can be eliminated in a photographic record by a suitable filter placed before the camera lens.[8] In the case of the continuous film movie camera, a slight vertical blurring of the scanning spot on the camera tube may be as effective.

SUMMARY

A television link with nonlinear circuits aids roentgen-ray movie production in allowing concentration on a small brightness range and also dose can be determined by the detail to be observed rather than by film properties. A continuously moving film camera viewing a single line on the kinescope, or a video magnetic tape recorder, need lose the effect of no interacting quantum. The frame rate aspect is considered and a systematic exposure procedure is given. A roentgen-ray beam energy monitor is also described.

The probable course of certain future developments is given as well as suggestions for the best use of existing detectors.

Radiological Research Laboratory
University of California Medical Center
San Francisco, California

The camera was constructed by Alan Cline, and John Kafafian investigated many of the circuit details. Dr. Earl Miller originated the recording of sound in this connection and also contributed to many stimulating discussions. Thanks are to be expressed to the Ampex Corporation for their loan of a video-tape recorder.

APPENDIX I

In connection with the evaluation of a roentgen-ray image in the form of a roentgenogram, it is convenient to have some measure of the possible information content of a film. The usual unit in information theory discussions is the bit.

One might estimate the number of bits of information in a standard 14×17 inch roentgenogram as follows. Suppose that each square millimeter can be significant, *i.e.*, there is no detail finer than this, but two such adjacent areas can be significantly different. And suppose each such area can have any one of a hundred distinguishably different densities. (For some applications this is a little unrealistic since one does not usually scan a film with a phototube and specify the absolute level at each point, except during television; the use of one's eyes is to distinguish any difference in intensity between two areas if it is more than roughly 1 per cent.) This implies approximately seven bits of information at each "point" since one would have to answer seven yes-or-no questions to state which of the 100 possibilities existed, *i.e.*, there are seven places of 0 or 1 in the binary number representation of 127, and six figures would only cover through 63 possibilities. The number of bits N at each region is:

$$2^N = 100 \quad \text{so} \quad 6 < N < 7.$$

Thus, the number of bits on such a film is roughly seven times the area in square millimeters, which is approximately a million.

Such a film could carry more than this by using its resolving power and exposure range to the maximum. The smaller films that are often used usually contain less information, but not necessarily less in proportion to their smaller area. This is because the finest recorded detail is usually smaller on such films. The information content of a small film would be as high as a large one if the small one were formed by clearly imaging a 14×17 inch fluorescent screen onto a small film of such resolving power that each unit area of the screen was still distinguishable.

The band width to transmit the above image at a 30 frame per second rate can be estimated by noting that a million choices between two voltage levels (*e.g.*, telegraph

key clicks) must be communicated in each 1/30 second interval. This will require a band width in cycles per second of approximately 30 million. This calculation implies the use of a binary code for transmission. Such a procedure is advantageous in the sense that noise will be less troublesome than if the signal level, from the hundred possible at each point, were sent directly, since the receiver need only be able to distinguish which of two levels exists at any instant. This signal sent in the usual way would require roughly a 5 megacycle band width. The source or nature of the noise must enter any detailed calculation of the band width required for the transmission of an image. A large roentgenogram can contain more detail than the above and require large band widths for faithful transmission if its quality is not attenuated by quantum fluctuations, screen noise, focal spot size, etc.

APPENDIX II

Present technology makes it conceivable that one can produce movies using spectral data to discriminate minute amounts of selected materials, and to enhance contrast generally over that found after ordinary roentgenographic processes that use lumped absorption information from many wave lengths. A scanning heterochromatic roentgen-ray beam would be used in conjunction with a very fast scintillation detector and pulse height analyzer (helped by delay-line pulse clipping) to record selected wavelength ranges in the emerging beam, rather than generating only a few discrete wave lengths, separated in time, as in the previous demonstrations.[2] For speed, it seems indicated that the equations giving the amount of the selected material[4] be solved by a simple analogue computer rather than being satisfied by the motion of wedges.

For example, if it is assumed that the qualitative analysis of the subject is two materials (soft tissue and iodine in the previous cases), then the two equations in terms of the four absorption coefficients of the two materials for the two wave length ranges, and the two intensity fractions k transmitted, are, for amounts of material t_1 and t_2:

$$\mu_{11}t_1+\mu_{12}t_2=\log k_1$$
$$\mu_{21}t_1+\mu_{22}t_2=\log k_2.$$

If material *one* is of interest then film blackening would be made proportional to:

$$t_1=\frac{\mu_{22}\log k_1-\mu_{12}\log k_2}{\mu_{11}\mu_{22}-\mu_{21}\mu_{12}}.$$

The denominator is constant in any one experiment.

In the previous method this signal would cause a compensating motion of a wedge of material *one*. In the present case, instead of wedges of the two materials being inserted in the apparatus, the corresponding μ's would be put in electrically. These can be determined from the original equations by noting the intensities transmitted at the two wave lengths by a unity density sample of material *one* when t_2 is zero, and vice versa. The main objection against not using wedges is that the variable number of emerging quanta per unit area indicates the application to the subject of some excess dose.[4]

In this method one quantitates the "hardening" of a beam as it traverses the subject. Rather than scanning with a special roentgen-ray tube like that of Moon, a lead Nipkow disk could be placed between the tube and the subject; a second one beyond the subject and moving synchronously with the first could help reject quanta that had scattered from the shorter wave length band into the longer. The use of ordinary filters and cycling Ross combinations is indicated to reduce the number of quanta from an ordinary tube that are in a useless wave length range, both for reasons of dose and also required detector speed. Special tubes in which there is composition modulation by an electron beam being shifted over a junction between target materials or by a roentgen-ray beam shifted over secondary emitters seem at present unduly complicated, though they would be

fast and feedback could maintain constant intensity. Methods related to the nondispersive infrared analyzers of the "negative-filter" type are also conceivable but more complex because roentgen-ray absorption spectra are not in the form of isolated lines or bands as in the infrared.

As an example of new results to be expected, calculation indicates that one can visualize inflammations by their more rapid uptake of large molecules[5] if these are iodine-labelled at a place where break-up will not too rapidly release the iodine to the thyroid. The same should be true of certain tumors which have a richer blood supply. It is here assumed that the finite energy resolving power of the detector does not impose a major extra limitation over the previous system using a special source, in which there are also technical performance limitations.

APPENDIX III

In graphs of the response of a system, sometimes linear and sometimes logarithmic coordinates are used. It is convenient to know the corresponding criteria for an increase in contrast in the two instances. It has been shown[2] that with linear coordinates there is an increase in contrast when the slope at the point in question on the graph of output intensity as a function of input intensity is greater than the slope of the line drawn from the point to the origin, that is, that dO/dI divided by O/I is greater than unity. On a logarithmic scale the slope is $d\ (\log O)/d\ (\log I)$. But:

$$d(\log O) = \frac{1}{O}\, dO \log_{10} e$$

$$d(\log I) = \frac{1}{I}\, dI \log_{10} e$$

or

$$\frac{d(\log O)}{d(\log I)} = \frac{dO}{dI} \Big/ \frac{O}{I}.$$

Thus with logarithmic coordinates, contrast will be enhanced at a brightness level that corresponds to a place on the curve where the slope is greater than unity. The photographic case is most familiar in which the maximum slope of film response is called gamma, and values greater than unity indicate increase in contrast.

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MEDICAL APPLICATIONS OF X-RAY TELEVISION

By HAJIME MATSUDA, M.D.,* TADASHI NAGAOKA, E.E.,† GORO TAKAI, M.D.,* *and* KAORU NINOMIYA*
OSAKA, JAPAN

SINCE the first medical application of the roentgen rays, continuous progress has been made both in the diagnostic and therapeutic domains in eliminating radiation hazards to which radiologists and operators of x-ray apparatus are exposed. Such fundamental means of protection as limiting the roentgen-ray beam by utilization of a multishutter and shielding the operator by walls of lead have proved of unquestionable value. The recent introduction of the image intensifier made possible remarkable further reduction in the exposure dose to the patient and the radiologist, and, at the same time, an improvement of detail perceptibility in fluoroscopy, but it still remained necessary for the radiologist to continue his studies in the fluoroscopic room, wearing a lead apron for protection. Why? The most important reason is that there has been no suitable optical device by which images on the photocathode screen of an image intensifier could be observed in another radiation-free room. In addition to this, it was rather difficult in practice to utilize the image intensifier alone in the fluoroscopic examination since its visual field was limited to a 5 inch circle. For this reason, an image intensifier and a routine fluoroscopic screen had to be used alternately or otherwise the image intensifier had to be moved in succession over several regions of the patient to perform a comprehensive examination. If a 9 or 11 inch image intensifier were utilized, the patient dose, as well as the scattered radiation dose to the radiologist during cineroentgenography or direct roentgenography on a tilting table, could likewise not be reduced substantially unless the television principle were applied. During the last few years, several reports concerning x-ray television have been published in Europe, the United States and Canada.[3–5] Since 1956, when the first attempt to utilize television in fluoroscopy was made by Nagaoka—one of the authors of the present paper—considerable research has also been carried out in Japan. In June, 1958, at the time that the construction plan of the Center for Adult Diseases—Osaka—was submitted, the authors projected the installation of an x-ray television system for practical use. Since August, 1959, when the closed circuit television for roentgen diagnosis in the Department of Radiology in the Center was installed, the basic and clinical examinations have been performed by this means. The purpose of the present paper is to report on the capability of the x-ray television unit, the first of its kind for practical use in Japan, and to discuss its possible applications.

EQUIPMENT AND METHOD

Description of the X-ray Television Device. As shown in Figures 1, 2 and 3, our x-ray television system consists of a high tension generator with a controller (maximum output: 50 ma. at 125 kv. or 500 ma. at 90 kv. for one second; and 3 ma. at 120 kv. for continuous use),* a Philips Symmetrix 90/90 tilting table with a rotating anode tube of 1×1 mm. focus, a Philips 5 inch image intensifier and a closed circuit television with a 14 inch and a 17 inch screen of the ordinary television picture tube for fluoroscopy and indirect roentgenography. In addition, a television camera and monitor for general viewing of a patient and a

* Manufactured by Shimazu Seisakusho Co., Ltd.

* The Department of Radiology, Center for Adult Diseases, Osaka—Seijinbyo Center (Director: Arao Imamura, M.D.).
† The Department of Electronics, Central Research Laboratories, Matsushita Electric Industrial Co., Ltd., Kadomacho, Osaka, Japan.

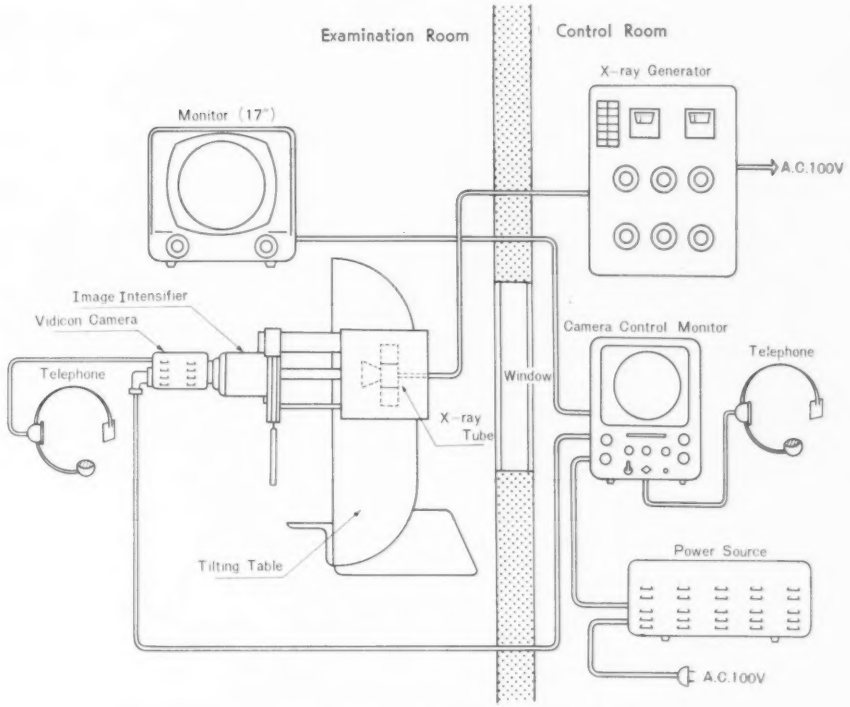

Fig. 1. General arrangement of the x-ray television equipment.

tilting table are provided.† Figures 3 and 4 show the television system in use.

Fluoroscopy. Radiologists can simultaneously view the fluoroscopic image through the television monitor screens, both in the control room (Fig. 3) and in the examination room (Fig. 4). Many physicians can take part in the fluoroscopic study with discussions by intertelephones in brightly lit rooms.

Roentgenography. Two different methods of roentgenography are possible with the television system: direct roentgenography on the tilting table and indirect fluororoentgenography through the television monitor. In the latter, the roentgen images on the 14 inch monitor in the control room are photographed either on 35 mm. roll films or by using 16 mm. cinefilms.

Detail Perceptibility. Seven groups of copper wires of different diameters (0.23, 0.25, 0.33, 0.4, 0.5, 0.6 and 0.7 mm.) are provided as a test chart for the examination of detail perceptibility. Each group consists of wires of equal diameter arranged on an extremely thin plate of plexiglass with the distances between them being equal to their diameters.

† The television system equipment is manufactured by the Matsushita Electric Industrial Co., Ltd.

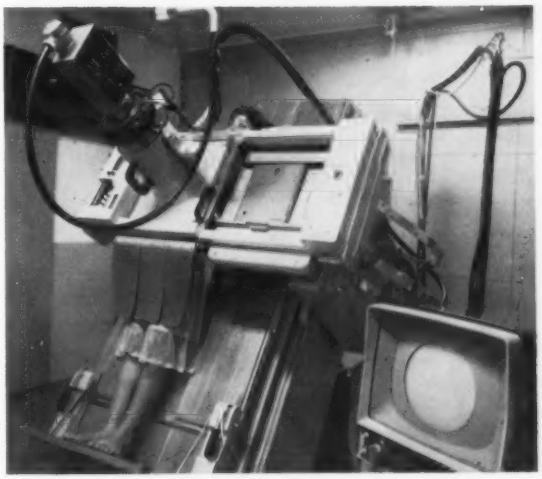

Fig. 2. Combination of Symmetrix 90/90 tilting table, 5 inch image intensifier and a closed circuit vidicon television camera with a 17 inch screen of an ordinary television picture tube for fluoroscopy.

FIG. 3. The control room of the x-ray television system. There are two television monitors; the left one is for telefluoroscopy, teleroentgenography and telecineroentgenography and the right one for a general view of the examination room.

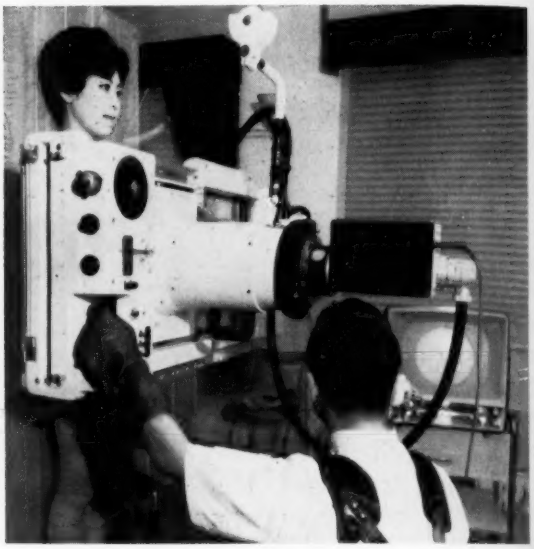

FIG. 4. The examination room of the x-ray television system.

Dose Meter. A Philips universal dose meter, type 37470, is employed. Ten plates of plexiglass, 30×30×1 cm. in size, and a plate of plexiglass, 30×30×5 cm. in size, are used as a phantom. These plexiglass plates can be added or reduced in number as the occasion demands.

Illumination Measurement on the Vidicon Faceplate. The direct measurement of illumination on the vidicon tube faceplate is difficult. Therefore, the luminous flux density at a fixed distance from the observation screen of an image intensifier is first measured by the use of a conventional illumination photometer. Secondly, by reproducing the same condition on an optical test bench, the illumination on the vidicon faceplate can be indirectly measured by the substitution method.

EXPERIMENTS AND RESULTS

TEST OF DETAIL PERCEPTIBILITY

A measurement of the detail perceptibility was performed using the copper wires with the smallest diameter of a group in which each of the wires was separately distinguished (Fig. 5, *A* and *B*). The detail perceptibility was evaluated with respect to: (1) fluoroscopy with the x-ray television monitor; (2) fluoroscopy with the image intensifier; and (3) fluoroscopy with the conventional fluorescent screen (Lerey-West "Sirius" HS screen).

The experimental data are shown in Figure 6; the distance of the focus to the photocathode screen of the image intensifier or of the focus to the conventional fluorescent screen was a constant 91 cm. The test chart was placed at a point 9 cm. from the photocathode screen of the image intensifier in the direction of the roentgen-ray tube when no phantom was used. With the phantom, the distance between the surface of the phantom facing the roentgen-ray tube and the focus of the roentgen-ray tube was always 58 cm. In the latter case, the detail perceptibility was evaluated by changing the depth of the test chart in a phantom 15 cm. thick; no detectable effect on the detail perceptibility was observed. Figure 6 shows that the detail perceptibility of the image intensifier is best, the x-ray television is slightly inferior to the former, and the conventional fluorescent screen is the poorest. As regards the detail perceptibility of the x-ray television system, one must take into consideration the fact that there is a significant difference due to the inclination of

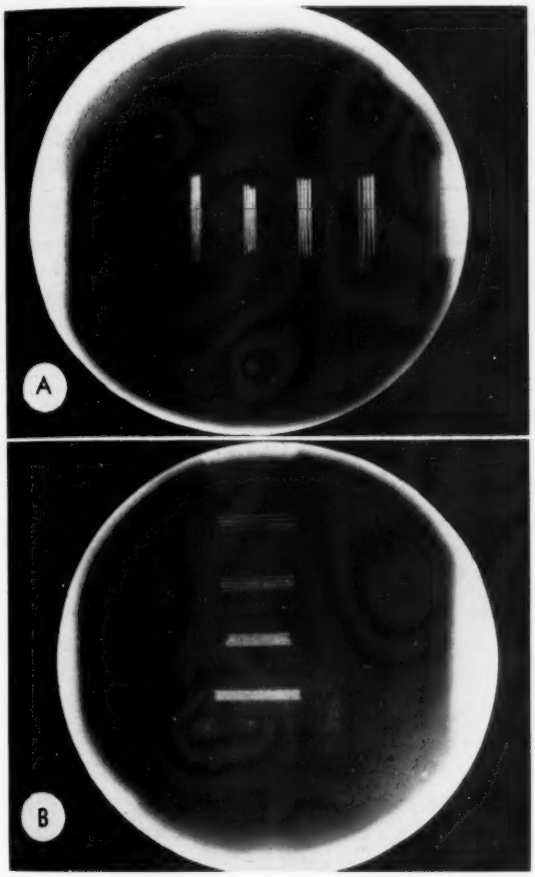

Fig. 5. Copper wires for the test of detail perceptibility. (*A*) The wires at right angles to the scanning lines of the television monitor are 0.4, 0.5, 0.6 and 0.7 mm. in diameter, left to right. (*B*) The wires parallel to the scanning lines are 0.7, 0.6, 0.5 and 0.4 mm. in diameter, top to bottom.

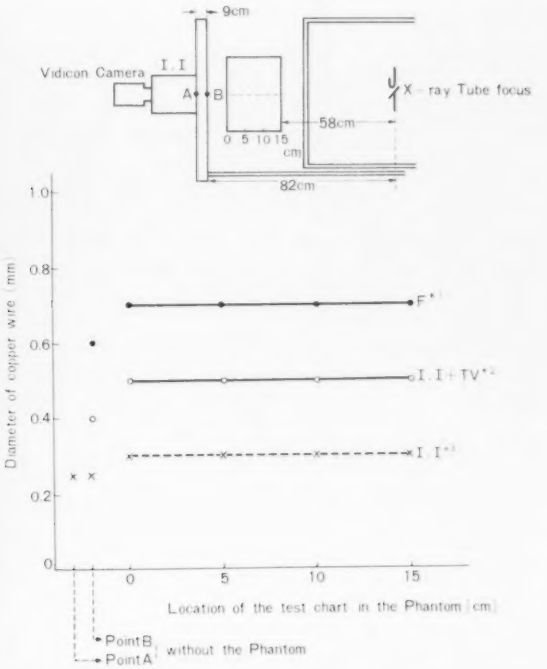

Fig. 6. Comparison of detail perceptibility of the fluoroscopic images by means of the conventional fluorescent screen, a combination of image intensifier and television, and image intensifier only.

Range of the diameters of the copper wires utilized for the test chart, 0.23–1.0 mm.; range of kilovoltage, 60–90 kv. peak; range of current, 2–3 ma.; focus size of the roentgen-ray tube, 1.0×1.0 mm.; grid ratio, 60–65/inch-24/cm.

*1 Conventional fluorescent screen.

*2 Combination of image intensifier and television.

*3 Image intensifier.

the copper wires of the test chart toward the scanning lines on the television monitor. When the wires are parallel with the scanning lines, the detail perceptibility is inferior by 0.1 mm. in diameter as compared to the case when the wires are vertical to the scanning lines (Table I and Fig. 5, *A* and *B*).

DOSIMETRY

The incident dose upon the object (*e.g.*, patient or phantom), the dose passing through the object and the scattered dose received during an examination were measured. The measurements were carried out by using the following factors: a 5 inch square roentgen-ray beam on the fluorescent screen, several kv. steps in the range from 60 to 120 kv., and currents of 2 and 3 ma.

Measurements of the Dose in the Plexiglass Phantom. The values of the incident dose upon a plexiglass phantom 15 cm. thick and the dose passing through it are given in Table II. That a relationship between the ratio of the exit dose to the entrance dose and the change of kilovoltage exists is evident (Fig. 7). Whether the x-ray television, the image intensifier or the conventional fluorescent screen is used, we can estimate roughly the patient dose received during fluoroscopy from this table. It was found that clear visualization of the pulmo-

TABLE I

COMPARISON OF JANKER'S AND THE PRESENT AUTHORS' DATA AS TO DETAIL PERCEPTIBILITY OF X-RAY TELEVISION SYSTEMS

Authors	Thickness of Phantoms (cm.)	Distance between the Test Chart and the Fluorescent Screen (cm.)	Minimum Diameter of Metal Wires That Are Distinguishable from Each Other (mm.)			
			F*	I. I.*	F+TV†	I. I.+TV*
Janker	0	0	0.4	0.3	0.8	0.6
Matsuda, Nagaoka, Takai, and Ninomiya	0	9	0.6	0.25	—	0.4 (0.5‡)
Janker	8		0.8	0.35	0.8–1.0	0.6
Matsuda, Nagaoka, Takai, and Ninomiya	15	9–24	0.7	0.33	—	0.5 (0.6‡)

* See Figure 6. F = conventional fluorescent screen; I.I. = image intensifier; TV = television.
† Combination of conventional fluorescent screen and television.
‡ Values in parentheses represent the detail perceptibility when the wires are parallel with the scanning lines of the television monitor.

nary field or the digestive tract with x-ray television was best accomplished by employing a current of 2–3 ma., and 70–75 kv. for the lungs (posteroanterior view), 75–80 kv. for the esophagus (oblique view), and 80–100 kv. for the intra-abdominal organs such as the stomach, the duodenum, the small and large intestines and the gallbladder. When the chest or the abdomen of a patient was thicker than usual, increase in the voltage did not show any appreciable improvement in detail perceptibility on the television monitor. From these clinical experiences and the experimental data, it seems to us that the necessary and satisfactory values in the ratio of the exit dose to the entrance dose are as follows: 0.7–1.0 per cent for fluoroscopy of the chest and 1.0–2.0 per cent for the abdominal organs (Table II and Fig. 7).

Measurement of the Patient Dose. We chose patients at random and measured the distribution of the dose in television fluoroscopy of the chest and abdomen with 2 ma., in relation to the thickness of the patient's

TABLE II

VALUES OF THE INCIDENT DOSE UPON A PLEXIGLASS PHANTOM 15 CM. THICK AND THE DOSE PASSING THROUGH THE PHANTOM USING A CURRENT OF 3 MA. THE ROENTGEN-RAY BEAM ON THE FLUORESCENT SCREEN WAS 5 INCHES SQUARE

kv.	Entrance Dose (r/min.)	Exit Dose (mr/min.)	Exit Dose / Entrance Dose (per cent)
60	1.57	14	0.82
70	2.36	28	1.10
80	3.15	48	1.52
90	3.88	75	1.93
100	4.66	100	2.14
110	5.32	125	2.34
120	5.50	148	2.69

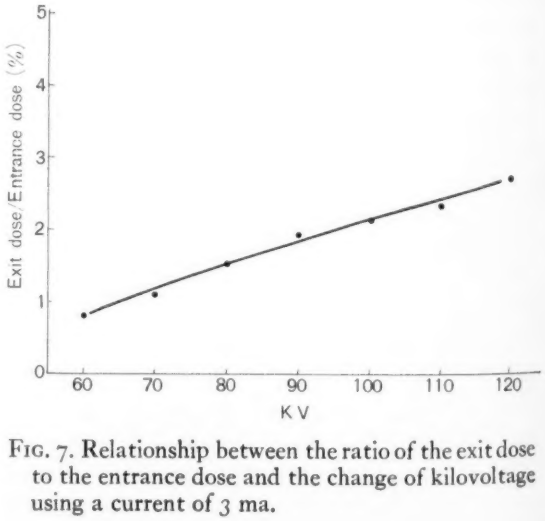

FIG. 7. Relationship between the ratio of the exit dose to the entrance dose and the change of kilovoltage using a current of 3 ma.

body (Fig. 8). The mean values were 2.0±0.3 r/min. for the chest and 3.4±0.7 r/min. for the abdomen. As may be seen from Figure 8, the thickness of the chest has no appreciable effect on the patient dose in fluoroscopsy of the lungs using television, although the dose increases gradually with the thickness of the abdomen in television fluoroscopy of the alimentary tract.

Measurement of the Scattered Ray Dose. The scattered ray dose of television fluoroscopy was measured perpendicular to the roentgen-ray beam at a point 100 cm. from the center of the phantom (Fig. 9), using 3 ma. and a 5 inch square roentgen-ray beam at the fluorescent screen. The amount of scattered radiation increases with increasing kilovoltage and the rate of increase is nearly linear up to 110 kv. As shown in Figure 9, at a distance of 100 cm. from the center of the patient, perpendicular to the direction of the roentgen-ray beam, the scattered dose will be approximately 0.15–0.2 mr/min. for examination of the chest, and 0.2–0.4 mr/min. for examination of the abdomen.

THE VIDICON FACEPLATE

The selection of the type of pickup tubes used for the television camera and also the

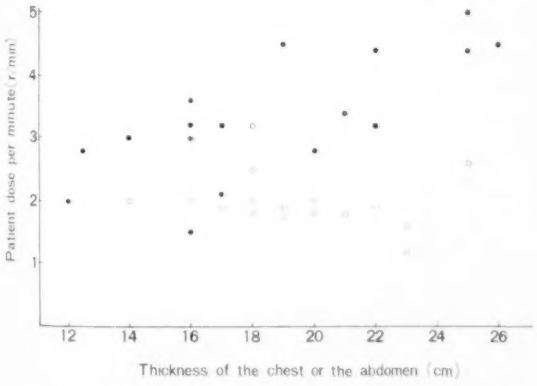

Fig. 8. Sharp contrast between the distribution of the patient dose in telefluoroscopy of a pulmonary field and that of an abdomen in relation to the change of the thickness of the patient's body.
○—Patient dose in telefluoroscopy of the lungs.
●—Patient dose in telefluoroscopy of the alimentary tract and gallbladder.

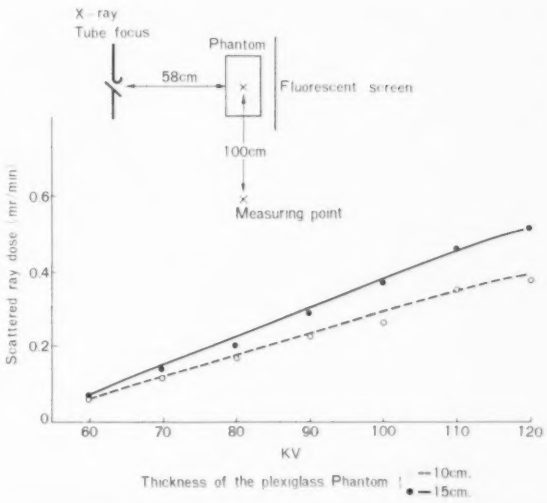

Fig. 9. Change of the scattered ray dose with change in kilovoltage using 3 ma. and a 5 inch square roentgen-ray beam on the fluorescent screen.

design of the head amplifier depend upon the degree of illumination produced on the vidicon faceplate by the roentgen-ray image focused through a proper optical system from the observation screen of the image intensifier. Figure 10 shows the result of our measurements, using the substitution method. As may be noted, the relation of the respective changes between the illumination on the vidicon faceplate and the thickness of a plexiglass phantom, with 3 ma. and various kilovoltages applied to the roentgen-ray tube, can be expressed in an exponential function. A plexiglass phantom with a thickness of more than 10 cm. must be considered extremely unfavorable as regards the sensitivity of the vidicon type television pickup tubes.

TELEFLUOROSCOPY AND TELEROENTGENOGRAPHY USING THE X-RAY TELEVISION SYSTEM

One of the most interesting characteristics of the x-ray television is that the radiologists can freely carry out teleroentgenography by using the monitor under conditions of routine fluoroscopy, while they perform telefluoroscopy with the same monitor. The technical factors for teleroentgenography are as follows: f=2.8; 35 mm.

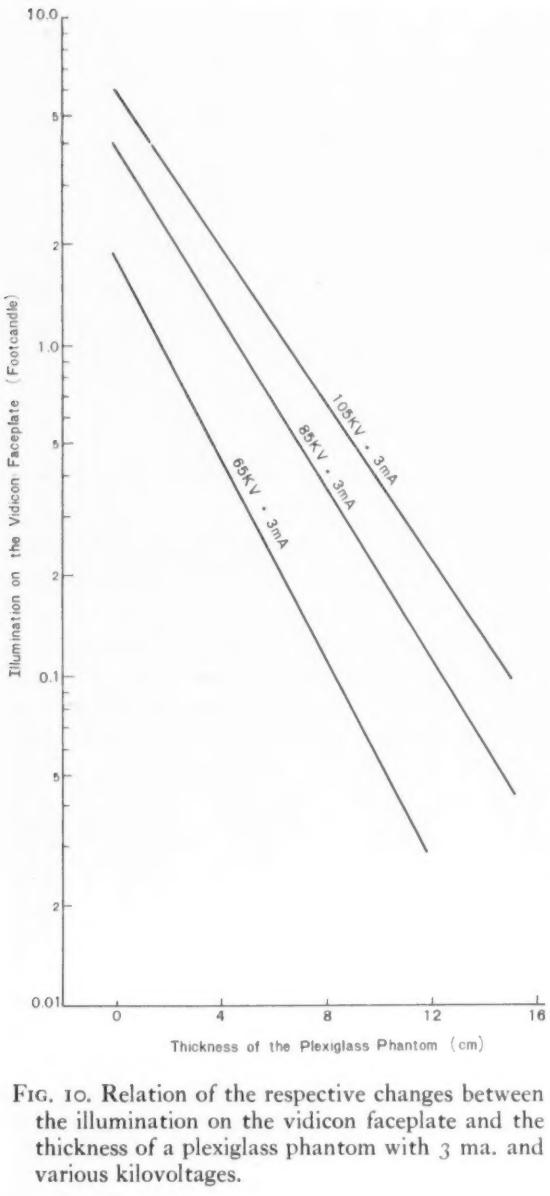

FIG. 10. Relation of the respective changes between the illumination on the vidicon faceplate and the thickness of a plexiglass phantom with 3 ma. and various kilovoltages.

Neo Pan SS, ASA 100 (Fuji) film; time of exposure = 1/10 sec.; distance = 3 feet, regardless of what part of the body is examined. Figures 11 to 13 illustrate indirect teleroentgenograms made by using the television monitor. It may be noted from these illustrations that the range of the x-ray television system is similar in teleroentgenography to that in telefluoroscopy, since both methods of examination are carried out under quite identical technical conditions and all regions of the body can be examined. However, it must be admitted that there is some difference in the ease of the examination depending on which part of the body is examined, as shown in Table III. This table was compiled from clinical experience with about 150 cases examined with x-ray television from October to November, 1959.

CINEROENTGENOGRAPHY USING THE X-RAY TELEVISION SYSTEM

Telecineroentgenography was performed by photographing the roentgen-ray images on the television monitor with a 16 mm. cinecamera (Arriflex) in the control room. The factors for telecineroentgenography were as follows: f = 5.6; Fugi x-ray film for fluorography; 15 frames/sec.; distance between the monitor and the cinecamera, 3 feet. Kilovoltage and milliamperage were the same as for telefluorography. Hence, the patient dose received during telecineroentgenography was equal to that received during telefluoroscopy, that is, 2–5 r/min. (Table IV). The regions examined by telecineroentgenography were the pulmonary fields, heart, aorta, trachea and bronchi after bronchography, the esophagus, small and large intestines after the ingestion of a barium meal, the sigmoid colon and large intestine after a barium enema, and the gallbladder after cholecystography using telepaque. Figure 14 shows clearly that telecineroentgenography using the x-ray television system is of definite diagnostic value in these regions.

DISCUSSION

Construction Problems. X-ray television units are roughly classified into two types depending on the kind of pickup tube employed. This is either the vidicon or the image orthicon. An example of the former is the Philips unit[1] and of the latter are Janker's[3] and Marconi's units. There are two fundamental reasons why we have adopted the vidicon camera system. The first is that the device with this system can be operated by radiologists without the

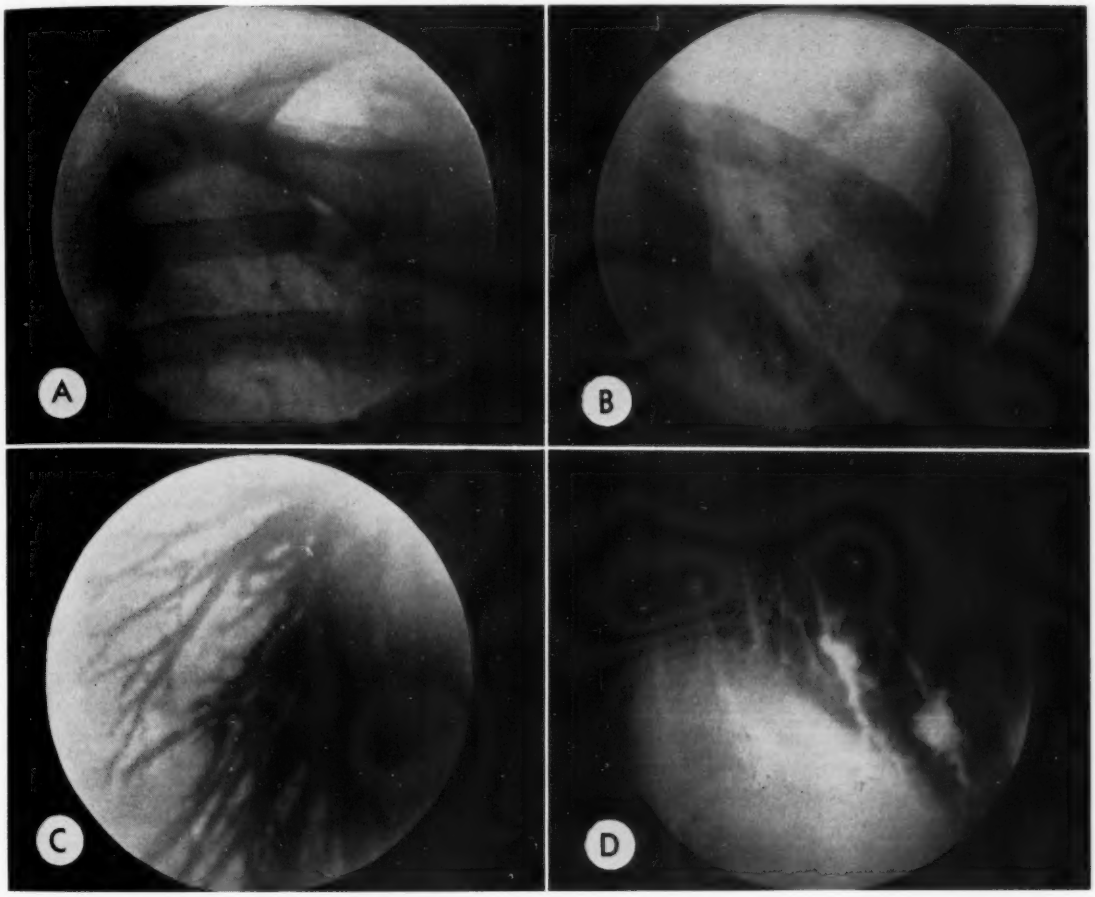

Fig. 11. Teleroentgenograms of the pulmonary field using the television monitor. (*A*) Upper region of the right lung field. (*B*) Lower region of the left lung field. (*C*) Normal bronchial tree. (*D*) Deformed bronchial arborization due to chronic bronchitis.

need of electronic engineers. Secondly, the signal to noise ratio of the televised roentgen-ray image is far better than that of the image orthicon camera. The image orthicon camera is, as is well known, extremely sensitive in comparison with the vidicon; therefore, it is capable of catching the image on the conventional fluorescent screen without the aid of the image intensifier, the use of which is indispensable to the vidicon camera. However, a comparison of Janker's[3] data with those of the authors' (Table 1) shows that the combination of the image orthicon camera and the conventional fluorescent screen leads to conspicuous deterioration in detail perceptibility, while the vidicon-image intensifier system is by no means inferior to the image orthicon-image intensifier system in the detail perceptibility. Under the circumstances we undertook a study of the x-ray television system by means of the vidicon-image intensifier combination. The sensitivity of the vidicon camera was not always satisfactory in the last few years, so the image orthicon camera has been temporarily used. It is our impression that the range of the image orthicon camera, in the future, will prove useful in particular problems.

Perceptibility Problems. These deal primarily with the focus size of the employed roentgen-ray tube. We have used a roentgen-ray tube of 1.0 mm. focus in our experiments. However, we found that a smaller focus of 0.3 mm. in size will give

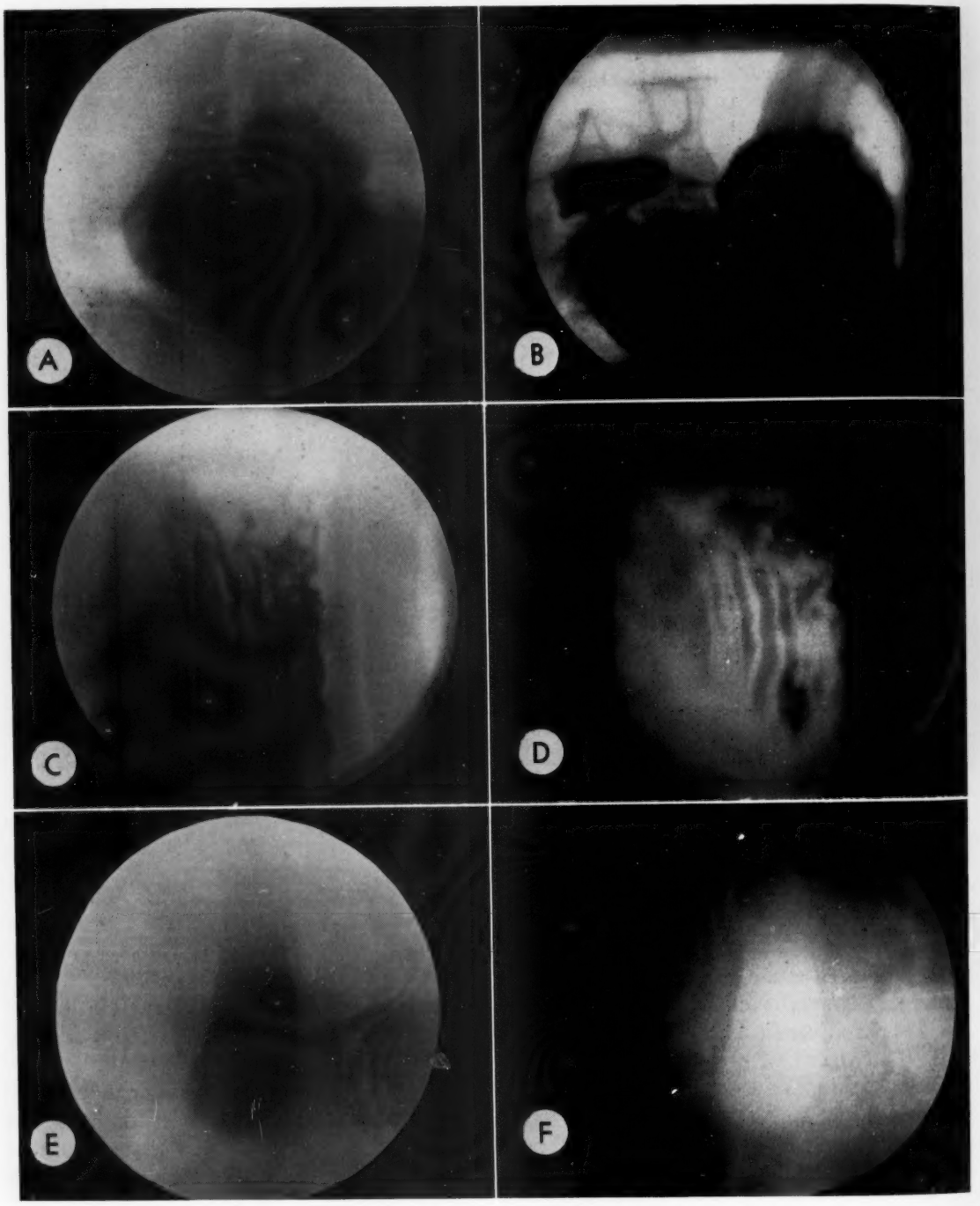

FIG. 12. Teleroentgenograms of the alimentary tract and gallbladder. (*A*) Prepyloric antrum, duodenal bulb and gallbladder. (*B*) Stomach and duodenal bulb. (*C*) Relief pattern of a stomach (positive view). (*D*) Relief pattern of a stomach (negative view). (*E*) Gallbladder (positive view). (*F*) Same gallbladder (negative view).

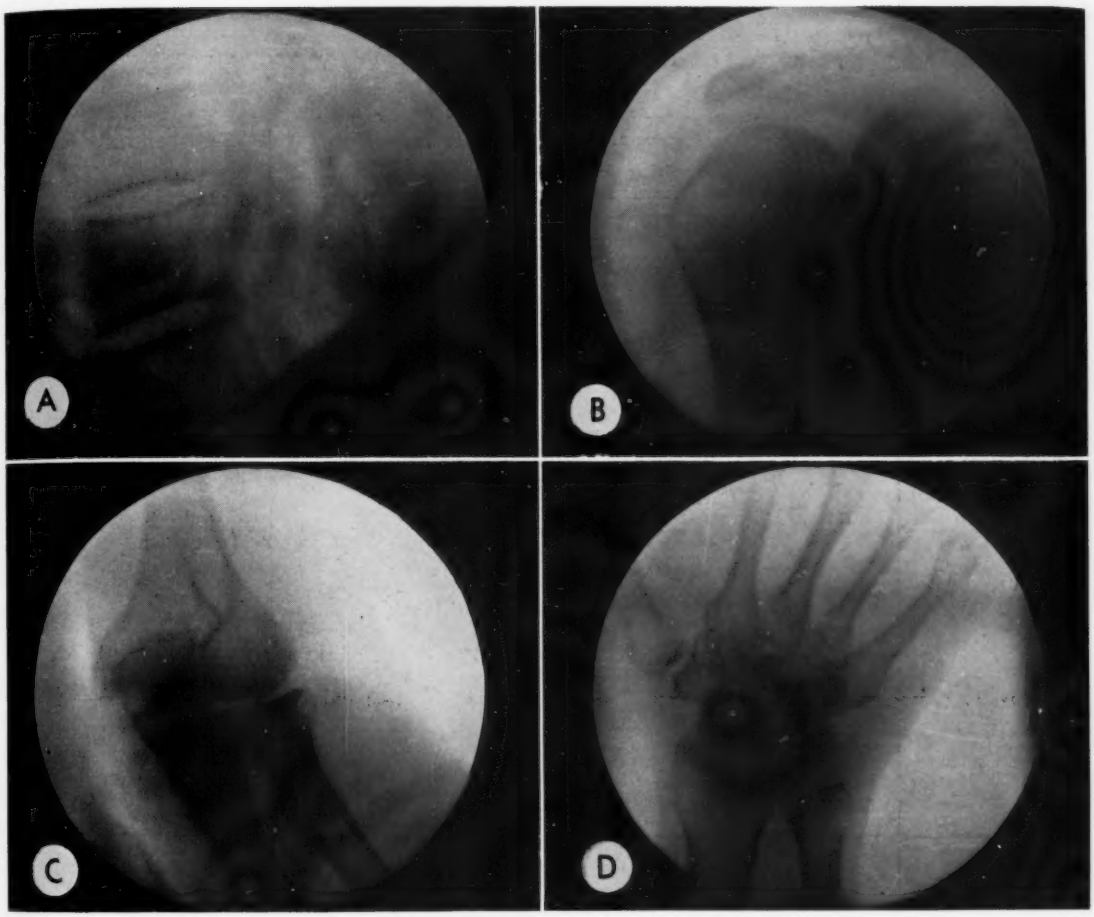

Fig. 13. Teleroentgenograms of bones. (*A*) Dorsal spine (lateral view). (*B*) Shoulder joint. (*C*) Elbow joint. (*D*) Wrist joint.

better detail perceptibility. Secondly, there is a slight difference in detail perceptibility depending on the direction of the object to the scanning lines of the television monitor (Table 1 and Fig. 5). With our present equipment, the difference in detail perceptibility is 0.1 mm. This is inherent to the 525 line square scanning system. We hope to adopt a 625 line system and thereby eliminate this difference.

Sensitivity Problems. Although our x-ray television system has a wide range of diagnostic possibilities in most regions of the body, it is, to an extent, limited. We were not able to get sufficiently clear images of the bony structures of the hip joint, head, upper dorsal spine and of the lateral view of the lumbar spine. Also, it was hardly possible to diagnose the lesions in the digestive tract of men who had an abdominal thickness above 25 cm. (Table III).

In order to overcome these difficulties, we feel that the following factors may prove helpful: (1) increase in milliamperage, (2) employment of a more sensitive vidicon tube in low brightness level, and (3) improvement in the efficiency of the optical component between the image intensifier and the vidicon camera. Usually, we employ a current of 2–3 ma.; however, we were able to get extremely clear images on the television monitor by temporarily increasing the milliamperage to 6 ma. without changing the kilovoltage (Fig. 12*B*). Our x-ray television unit is now under reconstruction with these points in mind.

TABLE III

CLASSIFICATION OF THE ORGANS OR REGIONS OF THE BODY ACCORDING TO THE EASE OF FLUOROSCOPY USING X-RAY TELEVISION

Ease of Fluoroscopy	Organs or Regions (nature of examination)	Direction of Roentgen-Ray Beam
Extremely easy	Lung	Posteroanterior, oblique
	Trachea and bronchi (bronchography)	Posteroanterior, oblique, lateral
	Heart and aorta	Posteroanterior, oblique
	Esophagus	Oblique
	Sigmoid colon and colon (barium enema)	Posteroanterior
	Cervical spine	Posteroanterior, lateral
	Middle and lower portions of a dosal spine (except D10 and D11)	Lateral
	Bones of extremities Shoulder joint Elbow joint Wrist joint Knee joint	Posteroanterior, oblique
	Bladder and urethra (cystourethrogram)	Posteroanterior, oblique
Easy*	Stomach Duodenum Small and large intestine (oral method) Gallbladder	Posteroanterior, oblique
	Lumbar spine	Posteroanterior
Rather difficult	Hip joint	Posteroanterior,
	Head	Posteroanterior, lateral
Difficult	Dorsal spine	Posteroanterior
	Upper dorsal vertebrae	Lateral
	Lower dorsal vertebrae (D10–D12)	Posteroanterior, lateral
	Lumbar spine	Lateral

* Clearness of fluoroscopic images as to these regions is influenced by the thickness of the abdomen. Hence, in general, the ease of telefluoroscopic diagnosis based on the thickness of the abdomen is as follows: under 20 cm. thick-easy, 20–24 cm. thick-moderately difficult, over 25 cm. thick-difficult.

In a future report, the experiences with the new unit and its diagnostic capability will be described. The timely introduction of the storage tube will make it possible to store electronically these extremely distinct images for any length of time without further radiation to the patient.

Effective Visual Field. The size of the effective visual field in the x-ray television unit of the vidicon tube and image intensifier system is limited by the diameter of the image intensifier. We now use a 5 inch image intensifier; however, it will be replaced by an image intensifier of a larger

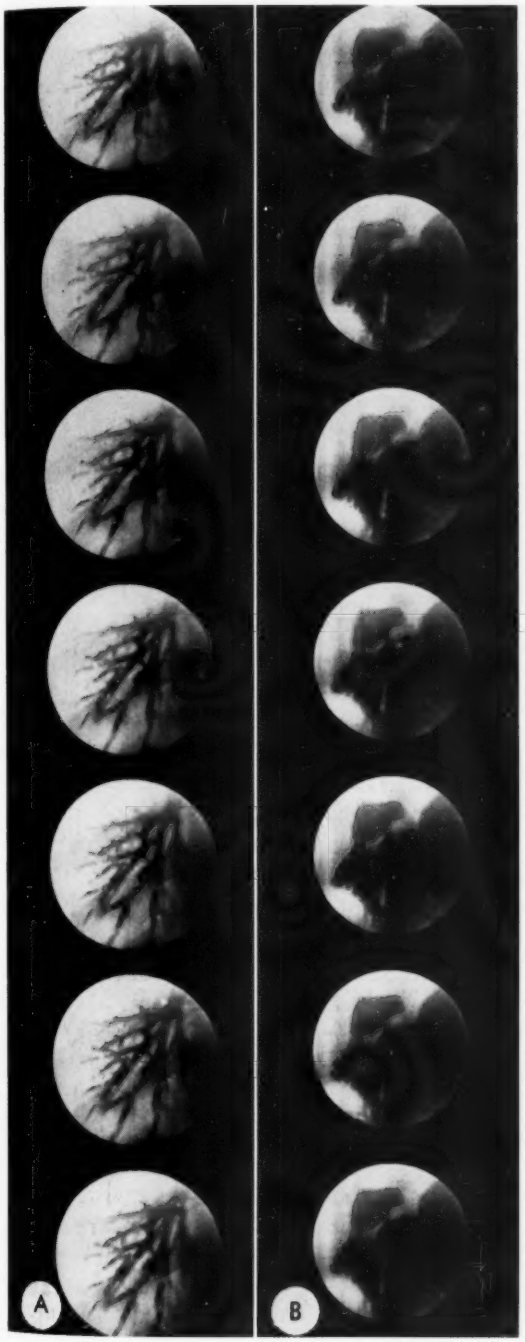

Fig. 14. (*A*) Telecineroentgenograms of a normal bronchial arborization, and (*B*) of the stomach and duodenum.

diameter. The 5 inch image intensifier is apt to be insufficient in clinical use and radiologists expend a great deal of work and time because of inevitable traveling of

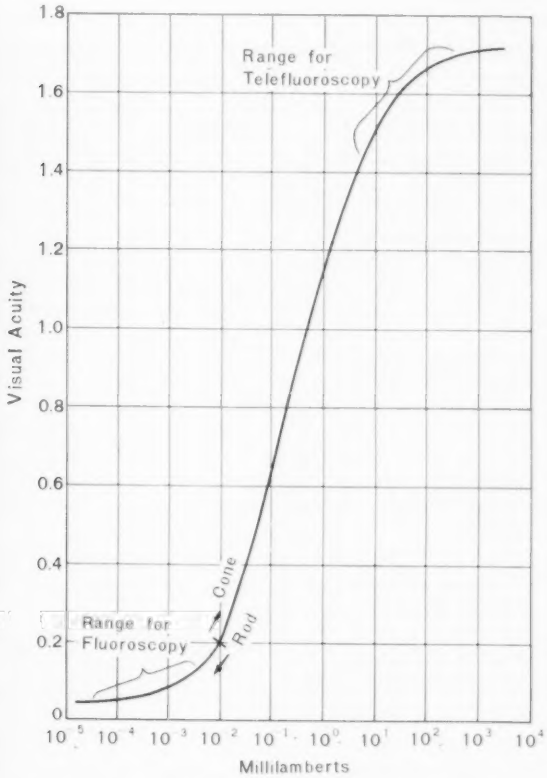

Fig. 15. Relationship of visual acuity to illumination; the brightness of the conventional fluorescent screen was in the order of 10^{-4}–10^{-3} millilamberts. Sharp vision is impossible at this low level brightness because observation takes place by means of the rods, localized at the peripheral parts of the retina, while with high brightness levels used in telefluoroscopy, observation is by the cones, situated at the central zone of the retina.

the visual field. Too, the necessary additional radiation exposure may bring about unfavorable effects. For these reasons an image intensifier of over 9 inches in diameter is recommended.

EVALUATION

Telefluoroscopy. Roentgen-ray images on the television monitor are very much superior to those on the conventional fluorescent screen in both brightness and sharpness. This means that the value of fluoroscopy—more exactly telefluoroscopy—is greatly increased in the domain of roentgen diagnosis. Hitherto, not only the inexperienced but also an experienced radi-

TABLE IV

RADIATION DOSE IN CONVENTIONAL CINEFLUOROGRAPHY AND IN TELECINEFLUOROGRAPHY

Method	Area	Authors	Kilovoltage	Milliamperage	Dose (r/min.)	Frames per sec.
Image Intensifier	Chest	Feddema	70	10	9	32
	Esophagus	Allcock and Barridge	95–120	6–17	13.5–42	16.6
	Stomach	Philips advertising	120	12	18	16
	Duodenum and small bowel	Feddema	120	11	20	16
Image Intensifier plus Orthicon	Chest and stomach	Janker	90	2–4	5–10	25
Image Intensifier plus Vidicon	Chest	Matsuda, Nagaoka, Takai and Ninomiya	65–70	2	1.5–2.5	15
	Esophagus		75–80	2	3	15
	Stomach, duodenum, and intestine		75–100	2	3–5	15

ologist would hesitate to make a positive diagnosis of diseases of the chest or digestive tract by fluoroscopy alone, without study of roentgenograms of those patients. Owing to the fact that there is 100,000 times as much brightness as on the conventional fluorescent screen (Fig. 15),[2] telefluoroscopy—fluoroscopy using the television monitor—is carried out by the conevision of the retina, while conventional fluoroscopy requires the rod-vision. This is probably the most important reason for the remarkable improvement of detail perceptibility in telefluoroscopy. When the detail perceptibility of the roentgen-ray shadow by means of telefluoroscopy becomes comparable to that of conventional roentgenography, it is possible that telefluoroscopy may replace direct roentgenography.

Indirect Roentgenography and Cineroentgenography. One of the greatest advantages of the x-ray television system is that the operator can freely take photographs of various organs of patients by means of a lens-shutter system camera or a cinecamera by using the x-ray television monitor during the course of fluoroscopy with complete protection against exposure to radiation. The authors again wish to emphasize that this type of indirect roentgenography, including telecineroentgenography, was performed with the same kilovoltage and milliamperage that they used in conventional fluoroscopy. This has an important bearing on the decrease of the patient dose in roentgen diagnosis. Telecineroentgenography—cineroentgenography using the x-ray television monitor—was performed at 15 frames per second because pictures are transmitted at 30 frames per second in our closed circuit television system.

Radiation Exposure of Patient and Radiologist. As regards radiation exposure, a line must be drawn between the dose received by the radiologist and that received by the patient. The radiologist and x-ray technician who are in the control room are completely protected against radiation throughout the course of fluoroscopy, roentgenography or cineroentgenography with the x-ray television monitor. However, since the tilting table which we now use is not remotely controlled, an operator is left in the examination room to select the visual field of the image intensifier, to roentgenograph directly and to tilt the table. We plan to remedy this by employing a fluoroscopic table operated by remote control.

The patient dose in telefluoroscopy, teleroentgenography and telecineroentgenography, regardless of whether the single or combined technique is used, is by no means greater than that in conventional fluoroscopy, but the relative patient dose in telefluoroscopy is greater than that in fluoroscopy using the image intensifier. For example, factors of 60 kv., 2 ma. for the chest and 75 kv., 2 ma. for the stomach and duodenum are adequate for obtaining clear images in fluoroscopy of patients who have a 20 cm. thickness of the chest and a 22 cm. thickness of the abdomen by using an image intensifier. In comparison, 75 kv., 2 ma. for the chest and 80 kv.–100 kv., 2 ma. for the abdomen are required in telefluoroscopy. Telecineroentgenography seems to have advantages over cinefluorography when the image intensifier is used (Table IV). In fact, cineroentgenography employing the x-ray television monitor appears to be one of the most useful techniques in the domain of roentgen diagnosis.

SUMMARY

The data concerning the construction and the diagnostic capability of an x-ray television system which is employed in clinical practice are presented. The advantages of this system to roentgen diagnostic procedures such as fluoroscopy, indirect roentgenography and cineroentgenography as well as the radiation exposure of the radiologist and the patient are discussed. Its contribution to definitive and efficient roentgen diagnosis is emphasized.

Hajime Matsuda, M.D.
The Department of Radiology
Center for Adult Diseases, Osaka
(Seijinbyo Center)
Minami 1-chome, Morimachi
Higashinariku, Osaka, Japan

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DETAIL VISIBILITY IN RADIOGRAPHS: THEORETICAL STUDY OF THE EFFECT OF X-RAY ABSORPTION IN THE OBJECT ON THE EDGE SHARPNESS OF RADIOGRAPHIC IMAGES*

By K. ROSSMANN, PH.D., *and* H. E. SEEMANN, PH.D.
RESEARCH LABORATORIES, EASTMAN KODAK COMPANY, ROCHESTER, NEW YORK

IMAGE sharpness is one of the numerous variables which influence the visibility of small details in a radiograph. The impression of sharpness gained by an observer is due to his reaction to stimuli received by his eye when it scans across the edge of an image on the radiographic film. These stimuli are some function of the density distribution at the edge which, in turn, is caused by the physical interaction of the penetrating radiation with the object and the film. Thus it appears that the final impression of sharpness is the result of a "chain reaction" passing from initial physical factors through physiologic reactions to the final subjective judgment. In short, sharpness is a psychophysical quantity. The question arises: "What is the link between the physical phenomena and the subjective judgment, or what measurable quantity makes one density distribution appear sharp and another unsharp?" The answer to this question is important because the density distribution on the film may be influenced by improved radiographic materials and techniques. In preparation for the investigation of this problem, it is of value to study the relationship between the density distribution in the image and the interaction of the penetrating radiation with the object and the film.

Physical factors affecting edge sharpness in radiographic images have been discussed by many authors.[1,4–9] Apart from certain characteristics inherent in photographic emulsions, *e.g.*, graininess, turbidity and developer effects, which limit the edge sharpness attainable, the following principal factors are usually held responsible for the unsharpness of a radiographic image: (a) movement unsharpness—caused by independent movement of the object, film, or source of radiation; (b) geometric unsharpness—arising from the finite size of focal spot or source of radiation; and (c) screen unsharpness—primarily due to the scattering of light in the intensifying screen.

Movement, geometric and screen unsharpness, separately and in combination, have been investigated theoretically and experimentally. They are often expressed in terms of the distance, measured on the image of an edge, over which the density changes continuously.

It is not clear, however, that this measurable quantity relates in general to the subjective impression of unsharpness. In fact, it will be shown later that this quantity cannot take into account certain additional physical factors, because in practical cases it may be impossible to define the endpoints of the interval by the simple statement that they are the points at which the density begins or ceases to change continuously. Also, it has been established for photographic images that sharpness is a function of density gradient at the edge,[2] and that a discontinuous density change (infinite density gradient) at the edge would give the impression of perfect sharpness. There is no obvious reason why a similar relationship should not apply for radiographic images.

In all cases, the derivations were based on the assumption that the object forming the edge had negligible thickness *and* was totally absorbing. Although this approach is instructive as a first approximation, it is felt that the restrictions are somewhat severe and that the results are unneces-

* Communication No. 2087 from the Kodak Research Laboratories.

sarily far removed from the actual phenomena. In reality, radiographic objects are, of course, of finite thickness and usually absorb only part of the radiation. The amount absorbed is dependent on the distance traversed by the radiation inside the object (as well as on wavelength, atomic number and specific gravity). When this is taken into account, it is apparent that it is impossible in practice to obtain a discontinuous change of photographic density at the image edge even if geometric, motion and screen unsharpness are negligible. This can be demonstrated mathematically for the following special case which is of interest as a first approximation to practical problems arising in medical radiography.

Let parallel penetrating radiation be incident perpendicular to the axis of a cylindrical object with the linear absorption coefficient μ_2 immersed in a material having linear absorption coefficient μ_1, and let us assume that the radiation is monochromatic and that no scattering occurs in the substances (Fig. 1). This situation is quite unrealistic, but it serves to demonstrate the effect of absorption in the object without the introduction of complicating factors. In a later study, some of the restrictive assumptions will be removed and the results will be more nearly applicable to practical situations.

From Figure 1 it follows that

$$\left(\frac{y_2}{2}\right)^2 + (r - x)^2 = r^2, \qquad (1)$$

where x is a linear coordinate measured in the film plane perpendicular to the axis of the cylinder, with $x=0$ at the edge of the cylinder and $y=0$ at the film plane. Then, solving equation (1),

$$y_2 = 2(2rx - x^2)^{1/2} \qquad (2)$$

and from Figure 1

$$y_1 = y_{11} + y_{12} = d - y_2. \qquad (3)$$

Now, for monochromatic radiation, the intensity in the film plane is given by

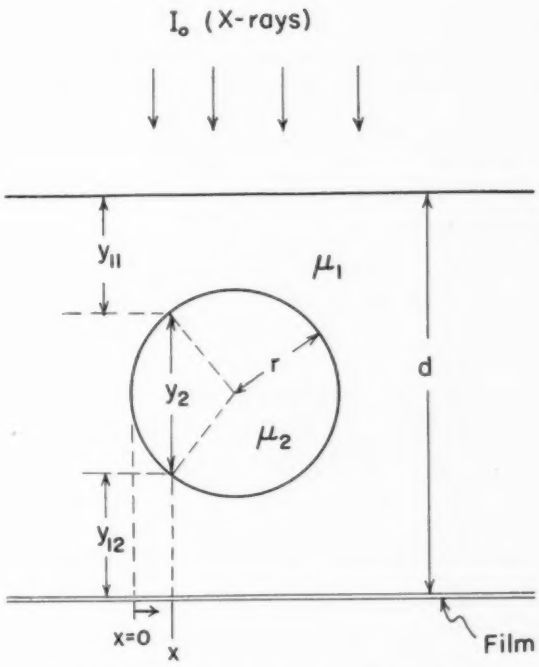

Fig. 1. Bone embedded in tissue (idealized).

$$I = I_0[\exp(-\mu_1 y_{11}) \exp(-\mu_2 y_2) \exp(-\mu_1 y_{12})]$$
$$= I_0 \exp[-(\mu_1 y_1 + \mu_2 y_2],$$

so that from equations (2) and (3),

$$I = I_0 \exp - [\mu_1 d + 2(\mu_2 - \mu_1)(2rx - x^2)^{1/2}]. \qquad (4)$$

It is not sufficient to describe the resulting image in terms of radiation intensity in the film plane as given by equation (4). The response of the viewer's eye is some function of the film density and contrast which are related to the radiation intensity by way of the characteristic curve of the film. Thus the image characteristics depend on the type of film used and the exposure and development conditions, in short, on any phenomenon which affects the characteristic curve. This will be demonstrated, using as an example the characteristic curves of Kodak Blue Brand Medical X-ray Film and of Kodak No-Screen Medical X-ray Film, both for direct x-ray exposures.

We can write, in general, for the density

$$D = f(\log E) = f(\log It),$$

TABLE I

LINEAR X-RAY ABSORPTION COEFFICIENTS OF MATERIALS COMMON IN MEDICAL RADIOGRAPHY[3]

Material	Density (gm./cm.^{3})	Atomic No.	Mass Absorption Coefficient μ_ρ (cm.^{2}/gm.) 40 kv.	Linear Absorption Coefficient μ(1/cm.)
Tissue (water)	1.00	7.42	0.1046	0.1046 (μ_1)
Bone	1.85	13.8	0.0945	0.1748 (μ_2)
Air	0.0013	7.64	0.0943	0.00012 (μ_1)
Subcutaneous fat	0.91	5.92	0.0941	0.086 (μ_1)

where the functional relationship is given by the characteristic curve of the film. Then from (4) and the relation,

$$\log A = 0.434 \ln A,$$

we have, for the exposure on the film,

$$\log E = \log (I_0 t) - 0.434[\mu_1 d + 2(\mu_2 - \mu_1)(2rx - x^2)^{1/2}]. \quad (5)$$

In order to obtain a quantitative description of the density distribution on the film by using equation (5), let us choose an example from medical radiography. Consider the cylindrical object to be a thigh bone (here assumed to be homogeneous) embedded in tissue. Then, approximately, $r = 1.5$ cm., $d = 20$ cm., and from Table 1, $\mu_1 = 0.1046$ cm.$^{-1}$ and $\mu_2 = 0.1748$ cm.$^{-1}$. Equation (5) then becomes

$$\log E = \log (I_0 t) - [0.908 + 0.061(3x - x^2)^{1/2}]. \quad (6)$$

In conjunction with the proper characteristic curve of the film (Fig. 2), equation (6) yields values for the film density, $D = f(x)$, due to the x-ray exposure, $E = It$. The value of $\log (I_0 t)$ may be chosen so that the theoretical density scale corresponds to the density scale often obtained in radiographs of this type. In order to facilitate comparison of the density distribution on the two types of film, we will select values for $\log (I_0 t)$ such that the density in the image of the tissue alone is about 1.7 for both films. The minimum density at the center of the bone will then be a function of the absorption of the object and of the contrast of the film.

Figure 3 shows a plot of the film density as a function of distance measured from the edge of the bone image. It is seen that the absorption of x-rays in the substances causes a continuous change of density extending from the edge of the bone to the

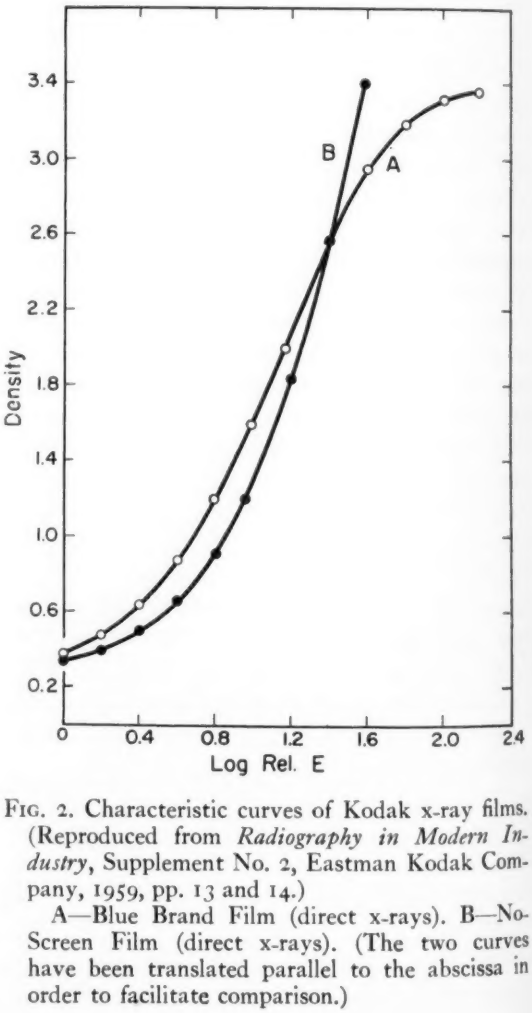

FIG. 2. Characteristic curves of Kodak x-ray films. (Reproduced from *Radiography in Modern Industry*, Supplement No. 2, Eastman Kodak Company, 1959, pp. 13 and 14.)

A—Blue Brand Film (direct x-rays). B—No-Screen Film (direct x-rays). (The two curves have been translated parallel to the abscissa in order to facilitate comparison.)

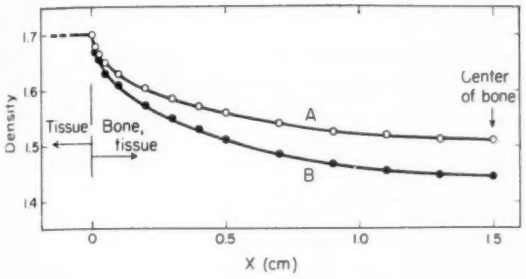

FIG. 3. Photographic density variation in the image of a bone embedded in tissue.

A—Blue Brand Film (direct x-rays). B—No-Screen Film (direct x-rays).

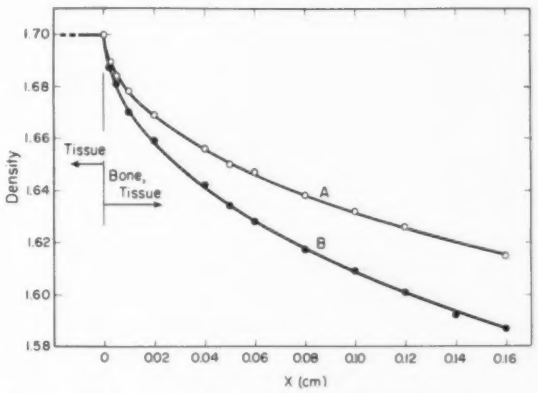

FIG. 4. Photographic density variation in the image of a bone embedded in tissue close to the boundary between bone and tissue. Scale expanded as compared with that in Figure 3.

A—Blue Brand Film (direct x-rays). B—No-Screen Film (direct x-rays).

center. The density gradient is obviously less than if the bone were square in section; further, the over-all contrast is decreased by the presence of tissue. These effects are of different magnitude on the two types of film. It will be shown in a later paper that, in the more practical case of diverging radiation, similar effects occur even when the object being radiographed is a plane parallel plate with a rectangular cross section. From these results it can be understood why it is impractical to express radiographic unsharpness in terms of the distance, measured on the image of an edge, over which the density changes continuously, as mentioned previously. Instead, it is reasonable to state that the subjective impression of sharpness is related to the density gradient at the edge of the image, as has indeed been shown for photographic images. Noting this proposed change in the measure of radiographic unsharpness, we may give the qualitative name "absorption unsharpness" to the subjective impression caused by the physical effects shown in Figure 3.

The density distribution close to the edge is shown on an expanded scale in Figure 4. It can be seen qualitatively how the absorption has reduced the density gradient (*i.e.*, the slope of the curve) as compared to the infinite gradient which presumably would give the impression of perfect sharpness. Using equation (5), one can determine how the density gradient at some fixed distance from the edge varies with the radius of curvature of the edge and with the relative magnitude of the absorption coefficients of the two substances.

From Figure 2 it can be seen that, for the small density range considered in this example, we may write for both types of film,

$$D = K \log E + C,$$

where $K = 2.07$ for Blue Brand Film without screens and $K = 2.77$ for No-Screen Film. Then, from equation (5),

$$D = K \log (I_0 t) - 0.434K \cdot [\mu_1 d + 2(\mu_2 - \mu_1)(2rx - x^2)^{1/2}] + C$$

and the density gradient becomes

$$\frac{dD}{dx} = -0.868K(\mu_2 - \mu_1)\frac{r - x}{(2rx - x^2)^{1/2}}. \quad (7)$$

Letting $r = 1.5$ cm. and choosing $x = 0.01$ cm., a distance which can just be resolved by the eye, we obtain the density gradient as a function of $(\mu_2 - \mu_1)$

$$\frac{dD}{dx} = -7.5K(\mu_2 - \mu_1).$$

Figure 5 shows a plot of this equation for both types of film. The points on the straight line correspond to bone immersed in air, fat and tissue. Values of $(\mu_2 - \mu_1)$ were obtained from Table 1.

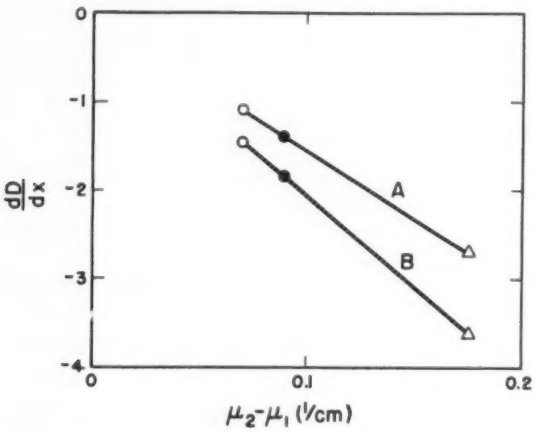

FIG. 5. Photographic density gradient in the image of a bone with 1.5 cm. radius embedded in: △ air; ● fat; ○ tissue. Density gradient measured at a point 0.01 cm. from the edge.

A—Blue Brand Film (direct x-rays). B—No-Screen Film (direct x-rays).

Figure 6 shows a plot of

$$\frac{dD}{dx} = -0.061K\frac{r-0.01}{(0.02r)^{1/2}}$$

obtained from equation (7) for the case of bone in tissue and $x=0.01$ cm.

Accepting the fact that the visual impression of sharpness correlates with the density gradient at the edge of the image, we can conclude from Figures 5 and 6 that sharpness should increase as the difference between linear absorption coefficients of the two bordering substances increases and as the radius of curvature of the object edge becomes larger.

Although the conclusions reached in this study are based on a greatly simplified example, they serve to demonstrate that the concept of absorption unsharpness should be added to the concepts of movement, geometric and screen unsharpness as another physical factor responsible for unsharpness in radiographic images. In fact, absorption unsharpness is peculiar to radiography because it stems from the very basis of radiography, namely, the ability of x-rays to penetrate matter selectively.

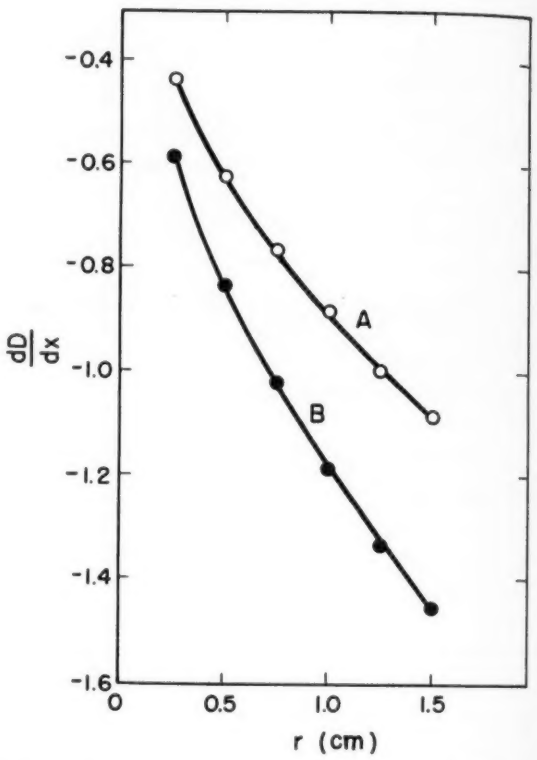

FIG. 6. Photographic density gradient in the image of a bone embedded in tissue as a function of the radius of the bone, measured at a point 0.01 cm. from the edge.

A—Blue Brand Film (direct x-rays). B—No-Screen Film (direct x-rays).

SUMMARY

The density distribution across the radiographic image of a cylindrical object has been calculated for an idealized situation, *viz.*, parallel, monochromatic radiation without scatter. The effects of the type of film used, the linear absorption coefficient of the object, and the radius of the cylinder on the density gradient at the edge of the image have been considered. It has been shown mathematically that radiographic "absorption unsharpness" results from absorption of x-rays in the object. An extension of this theory to more practical situations will be presented in the future and will be tested experimentally.

Research Laboratories
Eastman Kodak Company
Rochester, New York

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THE AMERICAN JOURNAL OF ROENTGENOLOGY, RADIUM THERAPY AND NUCLEAR MEDICINE

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* *Ex officio.*

EDITORIAL

FORD FOUNDATION GRANTS TO THE INTERNATIONAL SOCIETY OF RADIOLOGY FOR THE INTERNATIONAL COMMISSIONS

THE Ford Foundation, on October 10, 1960, announced grants to three important international scientific bodies "to help speed up the task of defining, measuring and limiting hazards resulting from man-made radiation." The International Commission on Radiological Units and Measurements (ICRU) received $185,000. The International Commission on Radiological Protection (ICRP) received $250,000.

The International Bureau of Weights and Measures, established by treaty in 1875, received $32,500; this Bureau is not connected with a Radiological Organization but will assist in the development of world-wide standards of radiation measurement.

The ICRU was established by the First International Congress of Radiology in London in 1925 and the ICRP by the Second International Congress of Radiology in Stockholm in 1928. The members of these Commissions are appointed by the International Congresses, with the advice of Radiation Scientists and Medical Radiologists, on the sole basis of competence and without regard to nationality or political governments. Throughout the past three decades the problems submitted to these Commissions have steadily increased in number and importance. Financial support of their work has not been easy to obtain. Their meetings were usually held every three years in association with the International Congresses.

At the Seventh International Congress in Copenhagen in 1953, the need for additional financial support for these Commissions was obvious, particularly to enable them to meet more frequently than once every three years. Furthermore, at this time there was danger of loss of control of these Commissions by Radiology to another international, pseudogovernmental body. To establish clearly the sponsorship of, and to keep the control of these Commissions under Radiology, direct contributions from an International Radiological Organization were needed, which could not be supplied by the International Congress. For these purposes, the International Society of Radiology was proposed; its organization was worked out by an international committee; it was adopted and put into operation at the Eighth International Congress in Mexico in 1956. A secretariat was established in Copenhagen under the supervision of Professor Flemming Nørgaard, Secretary-Treasurer.

The ICRU and the ICRP then began to operate under the continuing sponsorship of, and to receive financial support from, the International Society of Radiology, in behalf of National Radiological Societies, called "Member-Societies," in thirty-four countries. The importance to the Commissions of this arrangement was reported to the Board of Chancellors of the American College of Radiology in 1958 by Dr. Lauriston Taylor, Chairman of the ICRU; this new sponsorship made Foundations and other sources of funds more receptive to requests for aid. The American College of Radiology became the "Member-Society" representing the United States in the ISR.

The above-mentioned grants will be

issued in annual installments of $37,000 for the ICRU and of $50,000 for the ICRP over a period of five years. The announcement of the Ford Foundation, on October 10, 1960, further stated: "The Foundation's new grants will enable three experienced international agencies to broaden their consideration of radiation problems independent of the policies of governments.

"The International Commission on Radiological Units and Measurements and the International Commission on Radiological Protection have been dealing with radiation hazards since the early uses of x-rays and radium in the 1920's. The Commissions are completely independent, and are neither financed nor sponsored by any government or organization of governments. Their members are selected on the basis of scientific ability without reference to the national interests of their home countries.

"The work of each Commission is carried out largely by committees of scientists and is coordinated through periodic conferences and an international secretariat. The Foundation's grants will help the Commissions meet the increasing demands for their work and will be used for administrative and publication costs, travel funds, and other expenses.

"During the next few years, the International Commission on Radiological Units and Measurements plans to devote major efforts to developing improved units and methods of measuring radiation received by living matter. The methods now widely used are based on the roentgen, a unit that expresses the quantity of energy emitted from a source as x-rays or gamma rays but is of limited value in measuring total doses of radiation absorbed by living organisms.

"The International Commission on Radiological Protection, through its recommendations of safe levels of radiation exposure, has established the basis for the official standards of radiation protection adopted by many countries. In the light of recent scientific developments, it plans to re-evaluate these recommendations and to publish revisions of them."

Dr. Taylor stated, "An essential ingredient in the build-up of our funds has been, and will continue to be, the small but regular support of the International Society of Radiology."

Ross Golden, M.D.

University of California
Medical Center
Los Angeles 24, California

BOOK REVIEWS

Books sent for review are acknowledged under: Books Received. This must be regarded as a sufficient return for the courtesy of the sender. Selections will be made for review in the interest of our readers as space permits.

Radiological Examination of the Small Intestine. Second edition. By Ross Golden, M.D., D.Sc., Visiting Professor of Radiology, University of California at Los Angeles; Professor Emeritus of Radiology, Columbia University; Formerly, Director of Radiology, The Columbia-Presbyterian Medical Center, New York City. Cloth. Price, $28.50. Pp. 560, with 176 illustrations. Charles C Thomas, Publisher, 301–327 East Lawrence Ave., Springfield, Ill., 1959.

In the review of the first edition of Ross Golden's epoch-making book, "Radiologic Examination of the Small Intestine," the reviewer stated that "this publication marks a milestone in the advance of roentgenology, and should become the constant companion of every roentgenologist who hopes to qualify as such. It is no exaggeration to say that no more important or thought-provoking book has been issued in the field of gastrointestinal roentgenology and such a book would not have been possible without the writer having a thorough knowledge of the recent advances in physiology, neurology and chemical changes during the digestive processes."

The second edition of Doctor Golden's book has just been issued from the press of Charles C Thomas, Publisher. During the intervening years between the first and second editions, Doctor Golden has continued the assemblage of information which he thought to be most helpful in understanding the significance of the examination of the small intestine. In the pages of his book he applies the lessons of anatomy and physiology to clinical problems as they are disclosed by the roentgenologic method of examination.

There has been marked increase in our knowledge of the anatomic structures and the physiology of the small intestine since the first edition. The second edition is greatly augmented in size to incorporate this newly acquired knowledge and it describes how the roentgen-ray studies may contribute to a thorough understanding of the pathologic as well as the normal physiologic processes. Many new chapters have been added which greatly enhance the completeness of the study of the small intestine.

Doctor Golden's intensive studies in internal medicine before he began his career in roentgenology enable him to interpret various phases of the physiologic aspects of the gastrointestinal tract, particularly the small intestine; and he has brought to bear in the current issue of his "Radiologic Examination of the Small Intestine" certain areas of knowledge dealing with the chemical changes in the intestinal tract which add immeasurably to the value of this book.

In the introductory chapter of the second edition, Doctor Golden discusses the potential hazards to health by exposure to roentgen rays during diagnostic procedures, and he points out that any roentgen examination of the human should be carried out by those who are best qualified to protect the patient from excessive radiation. He also points out that, with all due regard for potential dangers from radiation, care must be taken to avoid depriving a patient of the benefit of a roentgen examination which may disclose an immediate hazard to his health or even to his life.

Every roentgenologist and those dealing with the radiologic studies of the gastrointestinal tract can ill afford not to have Doctor Golden's book as a constant companion, as in this book is disclosed all of our present knowledge in its application to a thorough study of the gastrointestinal tract, particularly of the small intestine.

The book has an adequate index which gives ready reference to any given item of interest. It is not only beautifully printed, but the reproductions throughout are of the finest quality. It is with pleasure that one is permitted to review a book of such fascinating interest and importance as this one. To Doctor Golden himself, nothing but thanks and praise should be offered by all physicians who are interested in the gastrointestinal tract for the consummation of such a superb book as the second edition of "Radiologic Examination of the Small Intestine."

Lawrence Reynolds, M.D.

The Year Book of Radiology (1959–1960 Year Book Series). Edited by John Floyd Holt, M.D., Professor, Department of Radiology, University of Michigan; Walter M. Whitehouse, M.D., Associate Professor, Department of Radiology, University of Michigan; Harold W. Jacox, M.D., Professor of Radiology, College of Physicians and Surgeons, Columbia University; Chief, Radiation Therapy Division, Radiologic Service, Presbyterian Hospital, New York City; and Morton M. Kligerman, M.D., Professor of Radiology and Chairman of the Department of Radiology, Yale University School of Medicine; Radiologist-in-Chief, Grace-New Haven Community Hospital. Cloth. Price, $10.50. Pp. 446, with 328 illustrations. Year Book Publishers, Inc., 200 E. Illinois St., Chicago 11, Ill., 1960.

This current publication in the series of yearbooks of Radiology upholds the fine traditions and sterling reputation established in past editions. Undoubtedly a majority of radiologists rely on this source for the latest pertinent information and technical developments in their field. The gleaning of the "wheat from the chaff" of radiologic literature has been painstakingly accomplished, and the condensed articles do not lack in readability. A good balance between diagnostic and therapeutic subjects has been obtained.

The editors state that the most popular subject material recently has dealt with biologic hazards of radiation. Angiographic evaluation of carotid and intracerebral atherosclerosis ranks a close second. A number of articles on rare, or foreign, pulmonary diseases are included because of their pertinence at this time of increasing world travel. Among others are those dealing with pulmonary paragonimiasis, bronchiectatic toruloma, and schistosomiasis.

Therapy articles bring recent and encouraging information on marrow transplants in leukemic children, supervoltage treatment of inoperable and recurrent lesions of the rectum and pancreas, melanomas, and soft tissue and osseous sarcomas. Extremely well-selected articles appear in the section on gynecology.

In both the diagnostic and therapeutic sections the editors refer to a number of outstanding articles, monographs, and books which cannot be adequately abstracted and should be read in the original. This of course holds true for any article of particular interest to the individual reader.

An uninterrupted series of these yearbooks of Radiology would seem to be one of the most valuable assets of the radiologist's library.

Arch H. Hall, M.D.

Diagnostica Radiologica delle Vie Biliari. By T. Braibanti, L. Rossi, and A. Maestri; all of the Istituto di radiologia dell'Università di Parma. Pp. 494, with 183 illustrations. Minerva Medica, Turin, Italy, 1958.

This volume is an extended description of the roentgen diagnosis of disease of the gallbladder and bile ducts. In Part 1, the authors discuss the preparation of the patient, the examination with and without a contrast medium, the use of extrabiliary contrast, special examinations following transparietal and transhepatic injections of contrast medium, postoperative cholangiography, the study of function, the effects of various drugs on the gallbladder and bile ducts, and the use of roentgen cinematography.

The second part of the book includes discussions of congenital anomalies, calculosis, hydrops, cholecystitis, calcification of the walls of the gallbladder, milk of calcium bile, pericholecystic adhesions, and tumors of the gallbladder and of the bile ducts. A chapter is devoted to functional disturbances of the biliary tract. Obstruction by extrinsic causes is thoroughly discussed and beautifully illustrated, as are internal and external biliary fistulas. An especially interesting chapter concerns so-called regeneration of the gallbladder following cholecystectomy. This is recognized as actually representing incomplete surgical excision. Ninety pages of bibliography close the book.

This volume is noteworthy because of the great detail with which each subject is treated. The authors have had extensive experience in the diagnosis of biliary tract disease, and the correlation of their findings with the observations at surgery is excellent. Some readers may find the length of the book to be excessive.

Cesare Gianturco, M.D.

Fractures, Dislocations and Sprains. By Philip Wiles, M.S. (Lond.), F.R.C.S. (Eng.), F.A.C.S., Honorary Consultant Orthopaedic Surgeon, The Middlesex Hospital; Past President of The British Orthopaedic Association, The Orthopaedic Section of The Royal So-

ciety of Medicine, and The Orthopaedic Section of The British Medical Association; Corresponding Member of The American Orthopaedic Association; Formerly, Hunterian Professor of The Royal College of Surgeons of England, Lecturer in Orthopaedic Surgery, at The University of London, and Brigadier, Consultant Surgeon in the Army; British Treasurer of *The Journal of Bone and Joint Surgery*. Cloth. Pp. 67, with 519 illustrations. Little, Brown & Company, 34 Beacon St., Boston 6, Mass., 1960.

This is a "jewel" of a book, especially for those studying or teaching roentgenology or orthopedic surgery. An amazing amount of material is presented in only sixty-seven pages, made possible partly by the use of a wide column format with grouping and cropping of the many excellent roentgenograms and the use of outlining in the text whenever possible. The facts are presented in a straightforward manner and in a crisp, brief, typically English style. The sketches which are used have been miniatured but are very clear and explicit. The outlines are used to good advantage to summarize material in certain areas. This book has little resemblance to the author's text book on orthopedic surgery and is much less wordy.

L. Carl Sultzman, M.D.

Low-Level Irradiation. Edited by Austin M. Brues. Cloth. Price, $3.75. Pp. 148. American Association for the Advancement of Science, 1515 Massachusetts Ave., N. W., Washington 5, D. C., 1959.

This volume consists of a collection of eight papers and attendant introductory and conclusive remarks presented at Indianapolis, December 30, 1957, at a symposium of the Section on Zoological Sciences of the American Association for the Advancement of Science under the sponsorship of the United States Atomic Energy Commission and the Division of Biological and Medical Research of the Argonne National Laboratory.

The presentations concerning scientific background deal with: (a) Natural and Artificial Radiation Background of Man (R. A. Dudley), (b) Meteorological Factors and Fallout Distribution (L. Machta), (c) Genetic Effects (E. L. Green), and (d) Somatic Effects (A. M. Brues); those covering implications of low-level irradiation are entitled: (e) Radiation As a Public Health Problem (D. E. Price), (f) Responsibilities of the Press (A. J. Snider), (g) Legal and Political Implications (C. Holifield), and (h) Science and Morality (C. W. Churchman).

The first two papers can be said to cover their subjects adequately and may be considered as true summaries of scientific information. The remaining two in the first section, though necessarily concise because of the broad scope of their contents, reveal the authors' skill in summarizing for the informed layman the status of extemely complex and only partially understood information.

The equally concise section on the implications of low-level irradiation illuminates sharply the impact which they have had upon our authorities and institutions. Readers only partially aware of these problems will find these articles to be worthwhile reading for they discuss the crux of the problem in a matter of fifty pages.

After a brief and useful summary of the conference, the editor brings the volume up to date by commenting on the relevant documentation which appeared in 1958.

L. D. Marinelli

BOOKS RECEIVED

Il Trattamento delle Lesioni Cutanee da Radiazioni. By Prof. Armando Isola, Libero Docente in Radiologia Medica, Istituto di Radiologia della Università di Genova, Genoa, Italy; and Dr. Leopoldo Bosio, Aiuto e Specialista in Chirurgia Plastica, Padiglione Mutilati del Viso, Istituti Clinici di Perfezionamento, Milan, Italy. Cloth. Pp. 218, with 81 illustrations. Minerva Medica, Turin, Italy, 1960.

Atlas of Tumor Pathology; Section iv-Fascicle 10a. Tumors of the Odontogenic Apparatus and Jaws. By Joseph L. Bernier, D.D.S., M.S., F.D.S., R.C.S., (England), Major General, Dental Corps, U. S. Army; Assistant Surgeon General; Chief of Dental Corps, U. S. Army; Former Chief, Oral Pathology Division, Armed Forces Institute of Pathology; Professor and Chairman of the Department of Oral Pathology, Georgetown University School of Dentistry, Washington, D. C. Paper. Price, $1.00. Pp. 107, with 120 illustrations. Armed Forces Institute of Pathology, under the Auspices of the Subcommittee on Oncology of the Committee on Pathology of the Division of Medical Sciences of the National Academy of Sciences —National Research Council, Washington, D. C.,

1960. For sale by the American Registry of Pathology, Armed Forces Institute of Pathology, Washington 25, D. C.

Diagnostica Radiologica del Cancro della Mammella. By G. Pisani, A. Malaspina, and G. Savino. Cloth. Pp. 162, with 140 illustrations. Minerva Medica, Turin, Italy, 1960.

Urethrographic Studies of Prostatic Tuberculosis. By Niels Bentzen. Translated from the Danish by Anna la Cour, née Claessen. Paper. Pp. 145, with 45 illustrations. The Finsen Institute, Copenhagen, Denmark, 1960.

Use of Radioisotopes and Supervoltage Radiation in Radioteletherapy; Present Status and Recommendations; Report of and Background Information for a Study Group Convened by the IAEA and WHO. Paper. Price, $1.50. Pp. 88. International Atomic Energy Agency, Kärntner Ring, Vienna 1, Austria, 1960. For sale by International Publications, Inc., 801 3rd Ave., New York, 22, N. Y.

Radiation Research; Supplement 2, 1960. Bioenergetics; Considerations of Processes of Absorption, Stabilization, Transfer, and Utilization; Proceedings of a Symposium Sponsored by the U. S. Atomic Energy Commission held at Brookhaven National Laboratory, October 12–16, 1959. Edited by Leroy G. Augenstine. Paper. Price, $10.00. Pp. 685, with numerous illustrations. Academic Press, Inc., 111 Fifth Ave., New York 3, N. Y., 1960.

Large Radiation Sources in Industry. Volume I. Proceedings of a Conference on the Application of Large Radiation Sources in Industry and Especially to Chemical Processes; Organized by the International Atomic Energy Agency; Warsaw, 8–12 September 1959. Paper. Price, $4.50. Pp. 478, with 300 illustrations. International Atomic Energy Agency, Kärntner Ring, Vienna 1, Austria, 1960. For sale by International Publications, Inc., 801 3rd Ave., New York 22, N. Y.

Strahlengefährdung und Strahlenschutz in der zahnärztlichen Röntgendiagnostik. By Professor Dr. med. Dr. med. dent. Theodor Kirsch, Oberarzt an der Universitätsklinik und Poliklinik für Mund-, Zahn- und Kieferkranke in Heidelberg. Paper. Price, DM 6,80. Pp. 59, with 47 illustrations. Dr. Alfred Hüthig Verlag, Wilckensstrasse 3, Heidelberg, Germany, 1960.

Les Rayonnements Ionisants; Calculs Techniques; Tables de valeurs numériques à l'usage des ingénieurs, radiologues, officiers. By Lucien Brunelet, Ingénieur de recherche industrielle. Paper. Price, $2.14. Pp. 74. Gauthier-Villars, Editeur—Imprimeur—Libraire, 55, Quai des Grands-Augustins, Paris (6e), France, 1960.

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ABSTRACTS OF RADIOLOGICAL LITERATURE

Department Editor: T. Leucutia, M.D., Harper Hospital, Detroit 1, Michigan

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ROENTGEN DIAGNOSIS

Neck and Chest

Sutton, Maurice. The functional effect of pulmonary irradiation. *Brit. M. J.*, Sept., 1960, *2*, 838–841. (From: Medical Research Council, Radiotherapeutic Research Unit, Hammersmith Hospital, London, England.)

While a number of workers have studied the effect of postradiation fibrosis on lung function, little is known about pulmonary function during the actual irradiation and in the period prior to the development of pulmonary fibrosis.

A number of patients undergoing irradiation of the lungs either directly, because of carcinoma of the bronchus, or indirectly, in cases of carcinoma of the breast, was subjected to lung function studies before, during and after treatment. The patients received roentgen irradiation from conventional 240 kv. deep roentgen-ray machines or from an 8 mev. linear accelerator. An attempt was made to show the difference in functional effect between the two forms of irradiation.

The author concludes that lung function tends to be depressed toward the end of the course of roentgen therapy at 240 kv. but that such depression was not seen with supervoltage roentgen therapy. This is attributed to the difference in radiation reaction. Moderate functional disability resulting from direct pulmonary irradiation by supervoltage roentgen rays was measured at the end of one year. No real functional disability resulted from roentgen therapy for carcinoma of the breast when modern therapeutic techniques were employed.—*Ralph M. Scott, M.D.*

Doubleday, Leonard C. Radiologic aspects of stab wounds of the chest. *Radiology*, Jan., 1960, *74*, 26–33. (Address: 1917 Ashland, Houston 8, Texas.)

In stab wounds of the supraclavicular region a chest roentgenogram, usually taken to determine the presence of pneumothorax, may demonstrate a widened mediastinal shadow resulting from hemorrhage into the mediastinum. Usually, as the pressure in the mediastinum mounts, the mediastinal pleura ruptures and an associated hemothorax develops. Prompt surgical intervention is indicated.

Initial anteroposterior supine roentgenograms of the chest in cases of suspected hemopericardium are difficult to interpret accurately, since it is estimated that 200 cc. of fluid may be present in the pericardial sac without altering the contour of the cardiac silhouette appreciably; however, many cases of proved hemopericardium show a straightened left border of the heart. The rapid accumulation of a relatively small amount of blood in the pericardial sac is sufficient to cause severe symptoms of acute cardiac tamponade which can be diagnosed accurately on clinical grounds when the roentgenologic findings are equivocal. Much larger amounts of fluid may accumulate slowly without causing death and serial roentgenograms may be necessary to detect the accumulation or the recurrence of bleeding or delayed exudative pericardial effusion. Angiocardiography may be necessary to exclude the possibility of persistent pericardial fluid when the cardiac silhouette appears to be within normal limits even in the presence of appreciable amounts of fluid. Although the present consensus of opinion is that hemopericardium is best managed by pericardial aspiration initially rather than by open operation, it would seem rational to believe that an opening in the parietal pericardium should be made as a secondary procedure if there is established evidence of persistent fluid, to permit drainage into the pleural space and to avoid delayed exudative pericarditis and adhesive pericarditis as possible late complications.

In penetrating wounds of the lower thorax, initial roentgenograms of the chest show little of note apart from pneumothorax. An abdominal roentgenogram should be taken initially, and serial roentgenograms of the abdomen and chest often reveal valuable information regarding occult intra-abdominal injury.

Several cases are briefly summarized to illustrate salient features.—*Walter H. Jarvis, Jr., M.D.*

Bateson, Eric M., and Abbott, E. Kathleen. Mixed tumors of the lung, or hamartochondromas. *Clinical Radiology*, Oct., 1960, *11*, 232–247 (From: Department of Diagnostic Radiology of the United Sheffield Hospitals and the City General Hospital, Sheffield, England.)

The authors review over 200 previously reported cases of hamartochondroma and report 15 tumors of this type from their personal experience.

The incidence of intrapulmonary hamartochondromas is estimated at 0.04 to 0.33 per cent of autopsies. Sixty-nine per cent occurred in males. Sixty-four per cent were found in the right lung.

Roentgenologically, the tumor is of two types, endobronchial and intrapulmonary. The former is rare, presents with signs of peripheral collapse, and cannot be differentiated from other endobronchial tumors. The intrapulmonary type is described as a well-defined round or oval tumor, most often lobulated and occurring peripherally. Eighty-two per cent are under 5 cm. in size. Irregular calcification was found in one-third of the cases, more often in the larger tumors.

An excellent differential diagnosis is given. It was found that a large mass (over 5 cm. in size) which has a lobulated outline and which contains irregular calcification is most likely a hamartochondroma. This is also a strong possibility in cases of small tumors with well-defined outlines, no calcifications, and no satellite nodularity. The use of laminagraphy

is urged to better outline the tumor and to detect the presence of calcium.—*Barry Gerald, M.D.*

CORNELIUS, EUGENE A., and BETLACH, EUGENE H. Silo-filler's disease. *Radiology*, Feb., 1960, *74*, 232–238. (Address: E. A. Cornelius, Hermann Hospital, 1203 Ross Sterling Ave., Houston 25, Texas.)

Since 1954, sporadic cases of pulmonary disease of unusual etiology have been encountered. The patients have a history of being exposed to nitrogen dioxide, a gas which forms in newly filled silos. Analyses of experimental lots of silage show that nitric oxide is the chief gas produced, which forms nitrogen dioxide upon contact with air. Nitrogen dioxide production reaches a peak within twenty-four hours of the time a silo is filled, and subsides in two or three days. It is a reddish brown gas, heavier than air, and quite irritating.

The illness following exposure is due primarily to the intensity and duration of exposure and secondarily to individual sensitivity. Mild exposure produces a catarrhal inflammation, while more serious exposure results in loss of bronchiolar epithelium, with fibrinous bronchiolar and peribronchiolar inflammation. Acute death from pulmonary edema is due to severe injury of the bronchiolar, alveolar, and capillary walls. Many changes have been observed in less acute cases, including bronchiolitis fibrosa obliterans, alveolar atelectasis, emphysema, bronchopneumonia, and focal interstitial fibrosis. Clinically, the typical illness may occur either as an immediate or a delayed reaction. Of 4 patients who had an immediate reaction, 2 died due to acute pulmonary edema. In the delayed group the illness is triphasic, with the acute phase coming on a few hours after exposure, then variable remission followed by relapse in two to five weeks.

Roentgenographic features have been nonspecific and variable and tend to lag behind the clinical course. Pulmonary edema with bilateral infiltration was observed in 1 case. Two cases of acute bronchopneumonia showed patchy confluent areas of infiltration, chiefly in the midlung fields, with later rapid and complete resolution. Six cases with bronchiolitis obliterans exhibited miliary nodulation at the height of the relapse, with roentgenographic resolution beginning about the fortieth day. One case two and one-half years after exposure exhibited no significant roentgenographic signs, although severe obstructive emphysema was present.

Final diagnosis is dependent on correlation of the history with the clinical and roentgenographic changes. The acute cases may resemble farmer's lung, and the differential diagnosis must be made on the basis of the date of silo filling and the presence or absence of an unusual gas. The delayed cases may be confused with pneumonia or tuberculosis, while bronchiolitis fibrosa obliterans may be differentiated from acute disseminated histoplasmosis by the history, greater clinical severity, smaller nodules, and absence of hilar lymphadenopathy. Metastasis and pneumoconiosis are excluded by nonroentgenographic means.

Treatment consists of the administration of oxygen and prophylactic antibiotics along with bed rest during the acute phase. Adrenal cortical hormone has been of value in treating the delayed cases during the relapse phase.

The authors review the literature of 13 reported cases and add 2 new case reports.—*James C. Moore, M.D.*

PETERSEN, JAMES A. Recognition of infrapulmonary pleural effusion. *Radiology*, Jan., 1960, *74*, 24–41. (Address: Massachusetts General Hospital, Boston, Mass.)

The present study consists of an analysis of 25 selected cases of infrapulmonary pleural effusion. Ten cases were associated with heart disease, 7 with malignant neoplasm, 4 with hypoproteinemia (nephrosis, cirrhosis), and 4 with inflammatory pulmonary or pleural disease. In 5 patients the process was bilateral; in the 20 with unilateral involvement, the effusion was on the right side in 14 and on the left in 6.

Typically, an infrapulmonary effusion presents itself on the posteroanterior upright projection as an apparently elevated leaf of the diaphragm, with a contour similar to a diaphragmatic shadow and just as dense. A characteristic form of this pseudodiaphragmatic shadow has previously been described as showing a gradual inclination upward and laterally from the cardiac shadow, with a rather abrupt drop near the costal margin to form a sharp gutter similar to a normal costophrenic angle; however, this occurred in less than 50 per cent of the cases studied. Recognition of the effusion on the left side is usually not difficult because of the unusual separation of the lung and the gas bubble in the stomach. In the lateral upright projection the pseudodiaphragmatic shadow is again seen, but more often only the midportion of the upper margin of the fluid is rounded and the posterior gutter is filled. An infrapulmonary effusion appears to reduce the volume of the lower lobe of the normal lung, while the remaining lobe or lobes seem to be unchanged in size and position. This produces a rather characteristic configuration on the upright lateral roentgenogram where the convex upper margin of the fluid meets the major fissure, forming a straight component of the pseudodiaphragmatic shadow anteriorly. In many cases the linear shadow of the major fissure above the effusion appears widened by the fluid entering the fissure. Lateral decubitus and supine roentgen studies may also be used to demonstrate the amount of hidden effusion, its mobility, and the true position of the diaphragm. Pneumoperitoneum

with upright roentgenograms may also be used to delineate the true level of the diaphragm and the exact level of the fluid. Fluoroscopy in the upright position ordinarily shows that diaphragmatic mobility is not impaired and that the upper border of the fluid maintains its contour and transmitted mobility; however, with suspended respiration, the upper shadow of the fluid may be seen to "shimmer" or undulate due to agitation by normal cardiac motion and, with deep expiration and lateral tilting, the fluid may be observed to spill out into the gutters and to assume the more usual appearance of pleural effusion.

The exact nature of the forces responsible for localizing fluid in this peculiar position is not known. In general, it is agreed that gravity is proabably the main factor when there is a pleural space that is free of adhesions and a healthy lung above.—*W. H. Jarvis, Jr., M.D.*

Bulgrin, James G., Dubois, Edmund L., and Jacobson, George. Chest roentgenographic changes in systemic lupus erythematosus. *Radiology*, Jan., 1960, *74*, 42–49. (Address: G. Jacobson, 1200 N. State St., Los Angeles 33, Calif.)

Systemic lupus erythematosus is a chronic disease subject to spontaneous remissions and exacerbations. A single organ system may be affected but the disease characteristically involves many organ systems resulting in extremely varied clinical manifestations. In recent years attention has been focused on the chest roentgenographic findings in this disease primarily because of conflicting opinions regarding the specificity of observed roentgen changes. The published reports, including single cases and large series, show disagreement both as to the frequency and type of roentgen findings. In general, the larger series of cases indicates that the roentgen changes are not specific.

Because of the conflicting reports, the authors conducted a study of the chest roentgen findings in 207 cases of lupus erythematosus. This study constitutes the largest reported series to date. The cases were classified as to the single and combined pleural, cardiac and pulmonary changes and the findings were further correlated with the duration of the disease.

The observed pleural changes consisted of effusion or pleural thickening and were present as an isolated abnormality as well as in combination with cardiac or pulmonary involvement. The abnormal cardiac changes consisted of nondistinctive enlargement, either isolated or combined with pleural and/or pulmonary involvement. The pulmonary changes were variable and nonspecific. Three cases exhibiting the variability of the pulmonary lesions are reported: one with infiltrative changes; one with manifestations of pulmonary edema; and one with extremely varied serial changes including the transient appearance of spherical lesions, one of which showed cavitation. It is interesting to note that no abnormality was present in 96 cases (46.6 per cent) which were not limited to the earlier stages of the disease.

The authors conclude that, due to the great variability in the reported series, one must be cautious in drawing conclusions on the basis of a single roentgenographic study. Although it is unusual, systemic lupus erythematosus may be present for many years and may even terminate fatally without a roentgenographically demonstrable thoracic abnormality. Combined involvement of the heart, pleura and lung is much more common than a single system involvement. Also, there seems to be a greater tendency for rapid change in pleural effusion and heart size in multisystem involvement than when the heart, pleura or lung is affected singly. Involvement of the lungs is less frequent than that of the heart or pleura and is not specific for the disease.—*Edward B. Best, M.D.*

Freimanis, Atis K., and Molnar, William. Chronic bronchitis and emphysema at bronchography; survey of diagnostic features obtained by reviewing 2,000 bronchograms. *Radiology*, Feb., 1960, *74*, 194–205. (Address: W. Molnar, Department of Radiology, Ohio State University Health Center, Columbus 10, Ohio.)

The purpose of this paper is to draw attention to the manifold bronchographic features of chronic bronchitis found in a study of 2,000 bronchographic examinations performed in a five year period at the Ohio State University Hospital.

The bronchographic criteria of chronic bronchitis vary greatly in range and quite frequently a variety of changes will be found simultaneously in one patient. The following changes have been observed in patients with chronic bronchitis and emphysema: (1) *Spasm.* On the bronchogram it is seen as a narrowing of the lumen with a gradual transition to normal caliber, and the extent of involvement varies greatly. The differentiation of spasm from organic obstruction may be made by close observation or repeated examination. (2) *Emphysema.* Bronchographic features include the "leafless tree" appearance, separation of the bronchial branches from each other, widening of the peripheral zones into which filled bronchial branches do not extend, bending and displacement of bronchi around emphysematous blebs, and thinnning of the peripheral bronchial branches. (3) *Increased and abnormal secretion.* This is indicated by defects along the bronchial wall or nonfilling of part of the bronchial tree. (4) *Obstruction.* This may be due to spasm, secretion, or disease causing destruction of the bronchial wall with subsequent scarring and obliteration of the lumen, in which case the differentiation between nonspecific inflammatory obstruction and neoplastic or specific inflammatory

obstruction (*e.g.*, tuberculosis) is difficult and usually has to be made on the basis of secondary evidence. (5) *Patchy alveolization.* This is due chiefly to obstruction or different rates of air flow in the smaller branches of the bronchial tree. The regular peripheral filling can range from relatively mild uneveness to a striking major "patchiness" of filled peripheral bronchioles and confluent alveolar filling with large surrounding areas devoid of any contrast material. (6) *Bronchiectasis.* This is the result of localized destruction of bronchioles with "pools" or "bronchiolectases" appearing as small round collections of contrast material. Occasionally there is cylindrical dilatation. "Spiders," possibly better called "peripheral shadows with spiked outline," are similar in origin and represent filled dilated bronchioles with several distended side branches and without further peripheral filling. (7) *Irregularity and deformity of the bronchial wall.* This is due to localized mucosal destruction, localized dilatation of the bronchial lumen, and fibrotic contractions in the more severe cases of chronic bronchitis. Initially the process may cause only irregularity of the bronchial outline. (8) *Dilatation of the larger bronchi.* Remarkable localized dilatations of some of the terminal branches may be found in association with chronic bronchitis, and represent an unusual type of bronchiectasis. (9) *Atrophy of the bronchial mucosa.* This is manifested by the appearance of annular areas of slight widening and narrowing of the lumen, thought to be the result of atrophic thinning of the mucosa. (10) *Mucous gland dilatation.* The distended mucous glands are usually seen as small extensions of contrast medium beyond the lumen of the bronchus, most often in the walls of the major bronchi. Their presence on bronchograms is characteristic of chronic bronchitis. (11) *Bronchial and tracheal inflammatory diverticula.* Rarely, multiple diverticula of the trachea are found. Single diverticula of the trachea or major bronchi are found more commonly, and are usually the result of a developmental error in the branching of the bronchial tree.

The pathologic findings obtained during bronchography are evidence of functional as well as morphologic changes and may provide detailed information necessary for accurate diagnosis and better understanding of the process. Through the use of bronchography valuable information may be obtained about an extensive part of the bronchial tree not accessible to other examinations.—*Walter H. Jarvis, Jr., M.D.*

JANIN, P. (Grenoble, France.) Intérêt de l'angiocardiographie dans l'étude des malformations pulmonaires. (The value of angiocardiography in the study of pulmonary malformations.) *J. de radiol., d'électrol. et de méd. nucléaire*, Sept., 1960, *41*, 432–439.

Cases are cited and roentgenograms are reproduced to show how angiocardiography may be of help in the diagnosis and demonstration of pulmonary malformations. Agenesis and hypoplasia of the lung, sequestration, abnormal venous returns, and some abnormalities involving emphysema or other forms of abnormal air retention are demonstrated. The angiocardiographic findings are not only of value in helping to make the diagnosis but are of great aid to the surgeon in helping predict the anatomic findings before surgery is contemplated.—*Charles M. Nice, Jr., M.D.*

DALITH, F., and NEUFELD, H. Radiological diagnosis of anomalous pulmonary venous connection: a tomographic study. *Radiology*, Jan., 1960, *74*, 1–18. (Address: F. Dalith, Government Hospital, Tel-Hashomer, Israel.)

An anomalous pulmonary venous connection is a congenital malformation in which one, several, or all of the pulmonary veins empty into the right atrium or one of its tributaries. This anomalous connection may be partial, in which case one or several, but not all, of the pulmonary veins empty into the right atrium or a systemic vein. Or the anomaly may be total, in which case all the pulmonary veins empty into the right atrium. The diagnosis of this anomalous connection is important as it is one of the anomalies responsible for a left to right shunt that is amenable to surgical treatment. Knowledge of the presence of this anomaly will also be of value to the surgeon doing cardiac or lung surgery.

The authors present a comprehensive review of the literature concerning this anomaly. In addition, a study is presented based on 9 patients in whom different types of the partial form and one of the total form of the anomaly were found. In this study the use of laminagrams was relied upon extensively to show the abnormal vascular morphologic details and to demonstrate the associated bronchopulmovascular malformations. This procedure may delineate clearly a disordered vascular pattern, the regions drained by the anomalous veins, the areas of lung traversed by them, the site of connections, and the width and shape of the vessels.

The authors stress, however, that although a surprisingly detailed anatomic diagnosis can be achieved by laminagraphy it cannot be relied upon alone if surgical treatment of this anomaly is planned. This is because not all forms of anomalous pulmonary venous connections can be demonstrated by this technique. Also, the presence of any associated malformation, the most common of which is an atrial septal defect, can only be demonstrated by other means such as cardiac catheterization and angiocardiography.—*Donald N. Dysart, M.D.*

BROUSTET, P., WANGERMEZ, CH., DUHAMEL, J., MARTIN, P. L., BRICAUD, H., and FONTANILLE, P. (Bordeaux, France.) Étude com-

parative des résultats des mesures du volume cardiaque par la méthode de stratigraphie axiale transverse et les méthodes géométriques téléradiographiques. (Comparative study of the results of measurements of cardiac volume by the method of transverse axial stratigraphy and teleradiographic geometric methods.) *J. de radiol., d'électrol. et de méd. nucléaire*, Sept., 1960, *41*, 417–431.

Several teleroentgenographic geometric methods for determining cardiac volume are cited, giving errors of about 6–16 per cent. These methods were compared with one using axial laminagraphy. Although the error is less than 10 per cent with the laminagraphic method, the other procedures are probably easier to carry out and have about the same degree of reliability.

It is concluded that cardiac volume is of more value in studying the evolution and prognosis of disease than in the original diagnosis.—*Charles M. Nice, Jr., M.D.*

Wolf, Bernard S. Roentgen features of the normal and herniated esophagogastric region. *Am. J. Digest. Dis.*, Sept., 1960, *5*, 751–769. (From: Department of Radiology, The Mount Sinai Hospital, New York, New York.)

Recognition of a sliding hiatus hernia more than 3 cm. in size presents little difficulty to the examiner. Below this size it is much harder to demonstrate, especially if the functional and anatomic regions of the distal end of the esophagus are not well known. In this article a detailed description of this area is presented. The author also emphasizes use of the epithelial ring to demonstrate small hiatus hernias.

Templeton's phrenic ampulla is discussed and it is pointed out that, of all the various sized sacs occurring during this phenomenon, the smallest sac that may persist and retain barium is *the* phrenic ampulla. This phrenic ampulla is enclosed above by the inferior esophageal sphincter (which is located approximately 1.5 to 2 cm. above the diaphragm hiatus) and below by the submerged segment. The upper level of the submerged segment is normally found at the diaphragm hiatus. The submerged segment itself is about 2 cm. long. Its distal end, called the cardiac antrum, merges into the stomach. In patients with hernias, the pinchcock action of the diaphragm can be used to indicate the level of the hiatus.

In reviewing Templeton's and Schatzki's rings, the author states that he feels both are anatomic gradations of the same thing, namely, the esophagogastric epithelial junction. He feels that demonstration of this ring above the hiatus is diagnostic of hiatus hernia.

In some patients with hiatus hernia the vestibule, which is composed of the phrenic ampulla and the proximal portion of the submerged segment, can be exactly delineated if both the inferior esophageal sphincter above and the esophagogastric junction below can be demonstrated. If the epithelial ring is not prominent, the vestibule and hernia appear as one sac. Under normal conditions, the vestibule is usually not evident as a single distensible region. However, sometimes it may be seen as a long empty segment between the esophageal segment and the distal portion of the submerged segment. It corresponds roughly to the sphincteric segment in the distal 4 cm. of the esophagus.—*William W. Joule, M.D.*

Abdomen

Leger, Lucien, and Crismer, Roger. Le radiodiagnostic des pancréatites chroniques. (The roentgen diagnosis of chronic pancreatitis.) *Acta gastro-enterol. belg.*, May–June, 1960, *23*, 396–449.

In a rather lengthy but meticulous manner the authors present the various roentgen examinations and findings for chronic pancreatitis.

1. Plain roentgenograms. Two types of calcification are noted: (a) Rather large calcifications about 10 mm. in diameter, with only one or a few located in the ducts; and (b) minute multiple calcareous deposits which may be either intracanalicular or within the parenchyma as part of a degenerative process in pancreatic tissue. These are best seen using both the anteroposterior and lateral projections.

2. Roentgen changes in the stomach and duodenum. When there is enlargement of the pancreas, such changes are distinct, but if the pancreas is atrophic and small there may be no demonstrable changes. The following are among the abnormalities to be looked for: (a) antral bulbar duodenitis, or antritis and duodenitis; (b) widening of the duodenal loop, which may be difficult to differentiate from carcinoma of the head of the pancreas; (c) deformity of the inverted "3" type, caused by pressure of the expanding head. (This also may be difficult to differentiate from carcinoma of the head of the pancreas.); (d) stenosis of the descending duodenum, which may also be seen with carcinoma of the head of the pancreas; and (e) edema and enlargement of the papilla of Vater.

When lesions involve the body and the tail of the pancreas there is enlargement of the retroperitoneal or retrogastric space with compression of the body of the stomach, deformity or displacement. There is disturbed motor function of the duodenum as well as of the antrum with irregular accentuation of the folds.

3. Roentgen signs following oral and intravenous cholangiography. In the absence of cholecystitis, with normal liver function, studies of the ducts present the following: (a) diffuse retraction, which is uni-

form or rectilinear in appearance, of the pancreatic and retropancreatic portion of the common bile duct; and (b) stenosis involving the region of the papilla with proximal dilatation of the common duct. The dilated duct often presents a right sided concavity due to pancreatic hypertrophy between the duodenum and common bile duct. This may not necessarily be diagnostic of pancreatitis as it may occur in carcinoma as well.

When oral or intravenous cholangiography is not feasible, the common duct may be visualized by transhepatic or peritoneoscopic cholangiography.

4. Laminagraphy following gastric and retroperitoneal insufflation. Using air in the stomach anteriorly and nitrous oxide for retroperitoneal insufflation posteriorly, the pancreatic mass is clearly defined anterior to the vertebral bodies.

5. Splenoportography. The value of this study is based on the close relationship of the splenic vein with the tail and body of the pancreas, and of the portal vein with the head of the pancreas. In chronic pancreatitis the splenic or portal venous systems are involved with compression and distortion occurring and with resultant hypertension as determined by manometric studies.

6. Pancreatography. This may be done by transparenchymal puncture into the main duct when it is dilated, by catheterization of the duct during a left hemipancreatectomy, or by transduodenal catheterization of the duct without prior sphincterectomy. The opacified duct will show such pathologic changes as dilatation, irregularity, narrowing, and constriction, as well as stenosis.—*William H. Shehadi, M.D.*

Baker, Hillier L., Jr., and Hodgson, John R. Further studies on the accuracy of oral cholecystography. *Radiology*, Feb., 1960, *74*, 239–245. (Address: H. L. Baker, Jr., Mayo Clinic, Rochester, Minn.)

In order to discover the degree of accuracy of cholecystographic diagnosis in the year 1957, the operative and pathologic findings of all surgically treated patients on whom cholecystograms had been obtained were correlated with the roentgen diagnoses. A total of 1,207 patients were available for this study. All these patients had been examined with the use of iopanoic acid (telepaque). The accuracy of the diagnoses in this series was then compared to that of two previous series in which iodoalphionic acid (priodax) only and iodophenoxic acid (teridax) only were used.

The results of this study showed that only 1.9 per cent of all diagnoses were found to be in error compared to 2.7 and 2.4 per cent error in the two previous series. This reduction in error was felt to be the result of eliminating the "avoidable" errors discovered in the earlier series and thus improving diagnostic accuracy. The use of iopanoic acid increased the number of gallbladders observed with higher concentrations of medium but there was no evidence that this increased opacity obscured tiny calculi or permitted visualization of abnormal gallbladders which did not contain stones.

An improvement in roentgenographic technique and interpretation was thought to account for the correct diagnosis of normally functioning gallbladders in 98.3 per cent of these cases. Fewer gallbladders were called "poorly functioning," apparently due to the use of the newer medium, iopanoic acid, and those that were given that diagnosis (3 cases) were found to be diseased.

Stones were found in 98.0 per cent of the cases diagnosed preoperatively as cholelithiasis. This is a slight decrease in accuracy from the previous series and was thought to be due to the misinterpretation of the findings made available as a result of the increased opacity of the medium. Polyps, papillomas, or adenomas were found in all cases in which they were reported. Among the gallbladders reported as nonfunctioning, 97.8 per cent were found to be diseased. This showed no change in the incidence of normal gallbladders in the nonfunctioning group.

The authors discuss in detail their actual procedure of cholcystography, including the preliminary preparation of the patient, the roentgenographic technique and positioning of the patient. Useful technical adjuncts such as the use of dihydroxyphenylisatin as a purgative, the use of a recently purified form of cholecystokinin to cause gallbladder contraction, and the use of radiolucent plastic foam blocks to afford compression of the gallbladder area are mentioned.—*D. N. Dysart, M.D.*

Genitourinary System

Abeshouse, Benjamin S., and Abeshouse, George A. Sponge kidney: a review of the literature and a report of five cases. *J. Urol.*, Aug., 1960, *84*, 252–267. (Address: B. S. Abeshouse, Urological Department, Sinai Hospital, Baltimore 5, Md.)

The sponge kidney is a term applied to a rare disease of the kidney first described in 1939. The present authors review the literature, from which they have collected 131 cases, and they add 5 personal cases.

The most striking pathologic feature of this disease is the presence of multiple small cystic cavities (1 to 3 mm. in diameter) confined to the pyramidal portion of one or both kidneys. These cysts may be spherical or irregular and are lined with pyramidal, cuboidal, or flat epithelial cells. The contents may be a clear fluid or fluid containing crystalline salts of calcium or varying sized calculi. Since the cysts connect with the pyelocalyceal system, they may be opacified by contrast substances used in pyelography. In the early cases, the kidney may be normal

or slightly larger than normal with no alteration in function. In later cases, deformity caused by calyceal compression from the pyramidal cysts or by infection, stone formation, pyelonephritis, and hydronephrosis may be seen on the pyelogram.

The etiology of this condition is not clearly understood but it is the consensus of opinion that faulty ontogenetic development is involved.

Sponge kidney is more frequent in males than in females and more frequently is bilateral than unilateral. Calculi are present in the majority of cases when first seen, probably because they are the factor which calls the attention of the patient and the physician to an abnormal kidney.

The diagnosis of sponge kidney may be made by intravenous or retrograde pyelography which will reveal the characteristic clusters of dye-filled cysts in the involved renal pyramids or the calculi in this distribution. Differentiation must be made from the microcystic form of polycystic disease, calyceal diverticula, ureteritis cystica, acute and chronic pyelonephritis with cystic changes, pyelogenic cysts, renal tuberculosis with cysts, nephrocalcinosis, and pyelotubular transflow.

No specific treatment is known for uncomplicated cases of sponge kidney. Usually these patients are asymptomatic until the development of some complication of infection, obstruction or stone and these complications are treated by the customary means. It is important, however, that the basic underlying pathology be recognized.—*George W. Chamberlin, M.D.*

Harrow, Benedict R., and Sloane, Jack A. Polycystic renal disease with renal and splenic artery aneurysms. *J. Urol.*, Sept., 1960, *84*, 447–452. (Address, B. R. Harrow, 2621 Biscayne Blvd., Miami, Fla.)

The present evidence indicates that the most likely cause of polycystic renal disease is a developmental defect in the germ plasm leading to numerous cystic formations in nephrons.

Polycystic disease of the kidney is associated with cystic disease of the liver and pancreas and with "berry" aneurysms of the cerebral vessels. Such congenital defects may be transmitted by a dominant autosomal gene.

A case report is included to illustrate the coincidental finding of left renal artery aneurysm, left splenic artery aneurysm, polycystic disease, and hypertension in a thirty-seven year old female. The questions which arose in the clinical evaluation and handling of this patient were: (1) should aortography be used to verify the finding of a ring calcification in the splenic artery region; and (2) should surgical treatment be utilized for a proved aneurysm?

It may be advisable to use aortography in young people with hypertension when there is a reasonable chance of repairing or grafting the renal artery. In these patients who have polycystic renal disease, nephrectomy is contraindicated.

The incidence of aneurysms of the renal and splenic arteries has probably been considered to be lower than recent facts indicate. Careful dissection of these vessels at autopsy and further evidence disclosed by aortography points toward a more accurate identification of these lesions.—*George W. Chamberlin, M.D.*

Hill, J. Edward, and Bunts, R. Carl. Thoracic kidney: case reports. *J. Urol.*, Sept., 1960, *84*, 460–462. (Address: J. E. Hill, Medical Arts Building, Richmond 19, Va.)

The authors present 3 patients in whom the left kidney was in an abnormally high position. This was visualized, on the roentgenogram, as a dome-shaped soft tissue mass in the left posterior thorax which might be mistaken for a hernia, neurofibroma or pleural cyst. The retrograde pyelogram demonstrated an elongated ureter with a high kidney showing a normal calyceal system. In one instance a pneumoperitoneum helped to make the correct diagnosis. This condition represents a congenital anomaly which may be associated with a herniation through the foramen of Bochdalek or a congenital eventration of the posterior leaf of the diaphragm.—*George W. Chamberlin, M.D.*

Fine, Myron G., and Vermooten, Vincent. Spontaneous extravasation associated with excretory urography. *J. Urol.*, Aug., 1960, *84*, 409–413. (Address: M. G. Fine, 616 Medical Arts Building, Dallas, Texas.)

The authors present 3 patients in whom extravasation of contrast medium was noted on intravenous pyelograms. All cases had ureteral colic and, in 2 instances, opaque calculi obstructed the ureteropelvic junction.

In the discussion of this phenomenon, the various studies of Hinman and Narath were noted. The authors believe that the lymphatics of the kidney play an important role in the drainage of the pelvic contents and may, in fact, act as a safety valve. When an excessive burden is placed upon the renal excretory system, a small lymphatic rupture may occur with spread of the contrast medium into the renal sinus, Gerota's capsule, and the peripelvic and periureteric areas.

The literature contains 32 cases of extravasation of intravenously injected opaque medium similar to those described in this article. Conservative management is recommended unless the subsequent physical signs and symptoms warrant further intervention. Three composite illustrations show the intravenous pyelographic extravasation.—*George W. Chamberlin, M.D.*

ROONEY, DONALD R. Post-voiding films as an aid to opacifying the obstructed ureter. *J. Urol.*, Aug., 1960. *84*, 300–306. (Address: Department of Radiology, Kennestone Hospital, Marietta, Ga.)

In this paper the author succinctly points out the value of a post-voiding roentgenogram in those instances of ureteral obstruction in which the site of the obstruction is not identified on the routine supine roentgenograms during intravenous urography. The technique consists of the simple expedient of allowing the patient to walk to the urinal and return to the x-ray room for a post-voiding roentgenogram. This procedure combines the advantages of delay in time, the use of gravity and agitation, and the change in ureterovesical pressures associated with micturition, all of which tend to enhance the value of subsequent roentgen studies. In the event that the patient is not ambulatory, the act of or effort at micturition may give added urologic information on the intravenous study.

Six composite illustrations of intravenous pyelograms are presented to illustrate the value of the method.—*George E. Chamberlin, M.D.*

BANSBACH, WILLIAM A., MAY, ROBERT E., and BOGASH, MORTON. Hypotonic bladder associated with sickle cell trait. *J. Urol.*, Sept., 1960, *84*, 470–471. (From: Surgical Service, Section of Urology, Veterans Administration Hospital, Philadelphia, Pa.)

The authors have found 4 patients with vesical hypotonia among 16 patients with sickle cell anemia. All patients were examined because of hematuria, which is not an uncommon sign in cases of sickle cell anemia. Cystometry revealed a greatly enlarged bladder (capacity, 1,100 ml.) with weak detrusor urinae contraction and reduced proprioception on bladder distention. No vesical neck obstruction was present.

In these patients with diminished sensory perception, the differential diagnosis should also include pernicious anemia, tabes dorsalis, and other spinal cord disease. The authors postulate that ischemic infarcts in the nervous system may cause bladder hypotonia, but the exact mechanism has not been identified.—*George W. Chamberlin, M.D.*

CHEYNET, M. MAURICE. Étude radiologique de la bilharziose urinaire. (Roentgenologic study of urinary bilharziasis.) *J. d'urol., Paris.*, April, 1960, *66*, 237–253.

Infestation with *Schistosoma haematobium* (bilharziasis) is very often associated with urinary involvement. The lesions are usually located in the terminal ureter, with stasis proximal to it. The resulting hydronephrosis leads to interstitial nephritis, frequently with irreversible parenchymatous damage. It is very important to know that these lesions are commonly asymmetric which permits surgery to be considered. However, it is better, if possible, to re-establish ureteral patency at an early stage, and thus to save the kidney.

The roentgen appearance, without a contrast medium, may be typical, inasmuch as the calcified parasitic ova deposited in the wall of the urinary bladder and in the lower ureters present very characteristic irregular ribbon-shaped, interlaced opacities interspersed with nodules of various densities and projected over the entire area of the urinary bladder.

After intravenous opacification of the urinary tract one may study the pelviocalyceal dilatations, although they are not characteristic. As stated above, the ureteral strictures as a rule are located in the distal two to three inches near the cystoureteral junction and in the vicinity of the calcifications which indicate the presence of ova.

There are millions of individuals suffering from urinary bilharziasis. Most of them reside in the tropics but, with modern transportation, one may find such a case in a temperate climate. The author, who lives in Madagascar, studied 43 patients with bilharziasis and in 29 of them he could demonstrate the existence of urinary tract involvement. In 9 patients, severe damage was found. Because symptomatology is very insidious, irreversible anuria may at times be the presenting symptom. Consequently, all patients known to have bilharziasis should have a thorough urinary examination, including intravenous pyelography.—*E. R. N. Grigg, M.D.*

SKELETAL SYSTEM

LEGRÉ, J., and SERRATRICE, G. (Marseille, France.) Aspects radiologiques des tumeurs primitives du rachis et leur traitement; (à propos de quarante observations). (Radiologic aspects of primary tumors of the spine and their treatment; [report of 40 cases].) *J. de radiol., d'électrol. et de méd. nucléaire*, May, 1960, *41*, 217–229.

Primary tumors of the spine are much less frequent than the secondary ones, which explains why they are not as well known. The authors were able to collect 40 cases of their own, all with histologic proof.

They have classified these tumors according to their tissue origin into: (1) tumors from skeletogenetic tissues (osteochondroma, chondroma, and the more exceptional tumors, osteoma, lipoma and periosteal fibroma); (2) tumors from reticulogenetic tissues (reticulosarcoma or Ewing's sarcoma, and plasmocytoma); (3) tumors of vasculo-connective origin (angioma, myeloplax tumor, and aneurysmal bone cyst); and (4) vestigial tumors (vestigium of notochordae).

These tumors were further classified based on the following factors:

Type. (1) In the osteolytic type, especially encountered in malignant tumors, the lysis may be localized or it may produce a partial vertebral collapse or, when more advanced, a complete collapse. Sometimes it may assume a pseudocystic pattern. (2) The proliferative type, observed mostly in benign tumors, may vary in form from a localized condensation to a proliferative neoplasm.

Location in the vertebral structure. (1) In the anterior three-fourths of the vertebra (22.5 per cent of their cases), it may produce a simple local osteolytic notch or, at a later stage, it may lead to a cuneiform vertebra. (2) The intermediate zone (45 per cent of their cases), including the posterior one-fourth of the vertebra and the pedicles, proved to be the most frequent site of the tumors. This area embryologically contains the intermediary ossification centers. The involvement of one or both pedicles will give on the anteroposterior roentgenogram a "one-eyed or blind" vertebra. On the lateral view, a lytic marginal notch may be seen on the posterior aspect of the vertebra. (3) Posterior location (7.5 per cent of their cases) is less frequent and usually the tumors are of the benign proliferative types.

In general, primary malignant tumors rarely give a characteristic picture and are confused with secondary malignant tumors, whereas the findings in many benign tumors are pathognomonic. The axis and curvature of the spine are little affected; there is no great gibbosity with the acute angle such as that produced in Pott's disease and little if any scoliosis or kyphosis is present. Moreover, the intervertebral disk is usually spared.

A detailed roentgenologic study of the various tumors is presented by the authors. They discuss in the malignant group, plasmocytomas, sarcomas and chordomas; and in the benign group, giant cell tumors, aneurysmal bone cysts, angiomas and chondromas.

In the therapeutic considerations, the authors discuss the role of surgery or radiation therapy used separately or combined. The results obtained with each of these techniques are presented.—*H. P. Lévesque, M.D.*

Wholey, Mark H., Pugh, David G., and Bickel, William H. Localized destructive lesions in rheumatoid spondylitis. *Radiology*, Jan., 1960, *74*, 54–56. (Address: M. H. Wholey, Mayo Clinic, Rochester, Minn.)

Certain patients with rheumatoid spondylitis show striking destructive changes involving the intervertebral disks and adjacent vertebral bodies. The changes closely resemble some type of infection such as tuberculosis, brucellosis, or a pyogenic condition. It is believed that the involvement of the intervertebral disk and adjacent bodies represents destruction by a chronic inflammatory process resulting from the spondylitis.

This manifestation of the disease is not widely recognized. Over a period of ten years (1947 to 1956), 10 patients with far advanced rheumatoid spondylitis and roentgenologic evidence of involvement of an intervertebral disk and adjacent vertebral bodies have been seen at the Mayo Clinic. The localized destructive lesions in all 10 cases were similar roentgenologically. Biopsy of the affected area in 2 patients showed chronic inflamatory lesions. In all cases the lesions failed to show the progression that would be expected of other infectious or granulomatous processes. In one patient there was evidence of spontaneous healing without specific treatment. All the patients were men. The average age at onset of symptoms was twenty-four years. In all instances, the disease had been in progress for at least ten years before exaggerated localized pain in the back led to further investigation. Roentgen examination then revealed destruction of the intervertebral disk and the margins of adjacent vertebrae. Destruction of the vertebral bodies was most pronounced anteriorly. Early destruction was soon followed by osteosclerosis of the affected segment.

One patient showed spontaneous resolution and subsequent ankylosis. In another patient, bone graft and fusion produced bony healing and relief of pain. All other patients were treated conservatively with a combination of body casts, antirheumatic drugs, and physical or roentgen therapy.

Three typical cases are reported in detail.—*Arno W. Sommer, M.D.*

Blood and Lymph System

Basu, S. P. Lymphangiography and venography in chronic filarial lymphoedema. *Indian J. Radiol.*, May, 1960, *14*, 89–98. (From: School of Tropical Medicine, Calcutta, India.)

The author studied the veins and lymphatic vessels in chronic filarial lymphedema. Lymphangiography was done in 33 patients with lymphedema and in 4 normal controls. The technique consisted of a preliminary subcutaneous injection of 11 per cent patent blue-V in distilled water given distal to the site of exploration. This stained the lymphatics so that they looked like blue threads when they were exposed by a skin incision. Seventy per cent diodone was rapidly injected into a vessel using a No. 16 or No. 18 needle. Roentgenograms were taken immediately and at two, five and eight minutes after injection.

In lymphedema of the scrotum, an incision was made at the junction of the scrotum and thigh, and 7 cc. of diodone was injected. There was good visualization of the lymphatics in 19 patients. Poor filling occurred in 5 patients with advanced disease. The opacified lymphatics were dilated and tortuous. The changes were most marked in the early stages of the

disease. In more advanced cases saccular dilatations and sudden narrowing were observed, but in general the opacification was poor. In early stages there was filling only on the side of injection and there was partial obstruction at the inguinal lymph nodes. With more advanced disease there was bilateral filling of the scrotal lymphatics due to collaterals and there was complete obstruction in the inguinal region on one or both sides. In later stages of the disease there was no filling or poor filling.

In studies of the lower extremity, 12 cc. of 70 per cent diodone was injected into a lymphatic vessel in front of the medial malleolus. In 6 patients the lymphatics were numerous and were markedly dilated and tortuous. Retrograde filling was observed, whereas this was not present in the 4 normal controls. The site of obstruction was in the mid-thigh and in no case was there opacification of the inguinal lymph nodes. In 2 patients with hard non-pitting edema there was little or no opacification of the lymphatics.

The breasts of 1 patient were studied by injecting 10 cc. of 35 per cent diodone into one of the skin vesicles (dilated lymphatics). In the right breast, which was less severely involved by the disease, the lymphatics were dilated and tortuous and there was good opacification of the afferent and efferent channels of an axillary lymph node. The lymphatics of the more severely involved left breast were poorly opacified and none of the opaque medium reached the axilla.

Venography was performed in 15 patients with lymphedema and there was no evidence of a significant abnormality in the involved upper or lower extremity.

The author believes that early in the course of filarial lymphedema the lymphatics become dilated. As the disease progresses they become narrow and occluded and collaterals are formed. He feels that stagnation and the accumulation of fluid rich in protein may cause hypertrophy of fibrous tissue. This leads to a permanent increase in the size of the part and explains the hard non-pitting edema seen in the late stages of filariasis.—*J. L. Williams, M.D.*

General

Alvarez-Borja, Arturo. Ellis-Van Creveld syndrome. *Pediatrics*, Aug., 1960, *26*, 301–309. (Address: Ahuachapan, El Salvador, Central America.)

The second recorded case of the Ellis-Van Creveld syndrome occurring in siblings is reported. The patients, brother and sister, presented with short stature, involving mainly the extremities, prominent abdomens, lumbar lordosis and genu valgum. Other physical characteristics were brachycephalic skull, lopped ears, abnormalities of the teeth, thinning of the upper lips in the midline, and supernumerary digits. No cardiac abnormalities were found. The laboratory tests were essentially negative.

The roentgen findings were basically as reported previously. There was generalized thickening and coarseness of the tubular bones, acceleration of maturation of the secondary centers and retardation of the primary centers of ossification. In the distal tibiae and fibulae there were areas of osteosclerosis intermingled with rarefactions. The heads of the radii and proximal ulnae were enlarged with narrowing of the opposite ends. Peaking of the proximal ends of the tibiae, described by Caffey as pathognomonic, was well illustrated. Curvature of the humeri was present. The thoraces were narrow with horizontal clavicles. The third cuneiforms were absent bilaterally in both cases. The articular spaces were normal.

The microscopic findings consisted of decreased osteoid formation and loss of columnar arrangement of the chondrocytes. The intrinsic mechanism responsible is not known.

The syndrome is apparently hereditary, transmitted recessively.—*Barry Gerald, M.D.*

Gorson, Robert Owen, Lieberman, Jesse, and Green, Marvin. A limited survey of radiation exposure from medical fluoroscopes. *Radiology*, Dec., 1959, *73*, 898–910. (Address: R. O. Gorson, Jefferson Medical College Hospital, Philadelphia 7, Pa.)

The authors present the results of a comprehensive survey of the radiation characteristics of 81 medical fluoroscopes. Twenty-two units were located in eight hospitals and four city clinics while the remaining 59 were in the offices of physicians in private practice. The data were obtained by questionnaire, physical inspection, measurement of radiation characteristics, and determination of radiation exposure to the physician.

The radiation measurements were made with the field size of the primary beam adjusted to 10×10 cm. at the panel surface or table top. The half value layer was determined by the inferential method whereby aluminum caps of varying thickness were machined to fit over the sensitive volume of a Victoreen 25 r condenser ionization chamber. A ratio of the chamber reading with the cap on to the reading with the cap off was calibrated as half value layer function. The half value layer calibration curve for aluminum caps as used here is independent of tube potential. All readings were taken with the chamber in the center of the field, in contact with the panel surface, and corrected to an exposure dose rate at the panel surface according to the inverse square law. Scattered and leakage radiation at various positions around the fluoroscope and in front of the fluorescent screen was measured by ionization rate meters. This information was used to calculate a "stray radiation index" (SRI) to allow comparison for machines and correlation with film badge readings. Fifty-three physicians were provided with two film badges each, with instructions

to wear one badge on the right arm and one on the left shoulder.

Data from the physical inspection of the fluoroscopic units disclosed wide variation from recommended safety precautions. About 40 per cent of the horizontal units and 97 per cent of the vertical units had target-to-panel distances measured or estimated to be less than 18 inches, the minimum distance recommended by the National Committee on Radiation Protection and Measurement (NCRPM). In the majority of machines, certain safety features for the fluoroscopist were absent in that the machine could be energized with the screen out of position, and, at maximal shutter openings, the recommended one-quarter inch of unilluminated screen was absent. Many fluoroscopes did not have metal tube housings or shockproof cables.

The results of radiation measurement likewise revealed a wide variation. One-half of all the fluoroscopes failed to meet the requirement that the exposure dose rate at the table top or panel surface not exceed 10 r per minute for routine fluoroscopy. Using a minimum acceptable half value layer of 2.5 mm. of aluminum, about 30 per cent of the fluoroscopes owned by hospitals and radiologists and 80 per cent of the units owned by nonradiologists failed to meet this requirement. The stray radiation index (SRI) was higher for fluoroscopes owned by hospitals and radiologists. This is undoubtedly due to the higher tube potentials and half value layer used by these groups. Only 17 per cent of the fluoroscopes failed to meet the maximum screen transmission requirement of 20 mr per hour. The film badge readings were low, with an average value of about 5 mr per week for the right arm and 2 mr per week for the left shoulder.

The authors recommend the following standards, as used in their survey, to assure a reasonable degree of inherent radiation safety: half value layer of at least 2.5 mm. of aluminum; table top or panel exposure dose rate of 10 r per minute or less; exposure at the screen not to exceed 20 mr per hour; SRI not to exceed 50 mr per hour; and no part of the primary beam should extend beyond the primary roentgen-ray barrier. Probably not more than a half-dozen units would have met all the criteria but fully 90 per cent could be made acceptable by adjustments in filtration, shutter opening, shielding, or milliamperage.

The basic principles of good fluoroscopic technique are discussed. The authors conclude that improvement in standards of fluoroscopic practice will continue to evolve primarily through the educational efforts of medical groups and institutions.—*Edward B. Best, M.D.*

RADIATION THERAPY

Scheidegger, S. Spätschädigung des Rückenmarkes bei Röntgenbestrahlung. (Late damage to the spinal cord after roentgen therapy.) *Radiol. clin.*, Mar., 1960, *29*, 65–70. (From: Pathologisch-anatomisches Institut der Universität, Basel, Switzerland.)

A case report is presented of late damage to the cervical spinal cord following intensive roentgen treatment of a squamous cell carcinoma of the pyriform fossa. The patient was a known hypertensive when he underwent treatment. Soon after completion of radiation therapy, he developed ataxia and sensory disturbances. He expired two years after treatment with the cause of death being a cerebrovascular accident. Autopsy findings showed extensive hyalinization of the walls of the vessels within the area of irradiation and a diffuse demyelination with ganglion cell degeneration of the lateral columns.

It is assumed that hyaline degeneration of the vessels was present at the beginning of the radiation treatment due to the hypertensive disease. Roentgen treatment aggravated this condition considerably, as the already damaged vascular walls seem to be more sensitive to the effect of irradiation.—*Eckart Schackow, M.D.*

Decker, K., and Lauter, H. The results of treatment of hypophyseal tumours; a retrospective survey. *German Med. Monthly*, Aug., 1960, *5*, 265–267. (Address: K. Decker, Universitäts-Nervenklinik, Nussbaumstr. 7, Munich 15, Germany.)

One hundred twenty-four cases of hypophyseal tumors are discussed. Of these 103 were followed for a period of two to twenty-five years. Approximately one-third of these had features of acromegaly. Surgery was performed on 50 per cent of the cases while roentgen therapy was the initial treatment in the other 50 per cent. Surgery was performed by the transfrontal approach. Roentgen therapy was done with Kohler's apparatus. The field size was 3 or 4 cm., according to tumor size. The submaxillary field proved especially useful in a few acromegalics because it gave good dosage distribution with decreased irradiation of cranial nerves. This apparently was only possible because of the acromegalic physiognomy. Of the operated cases, 17 were eosinophile adenomas and 56 were chromophobe adenomas. The operative mortality was 16.4 per cent.

The rate of recurrence was low for both roentgen and surgically treated groups. Of 103 patients, 72 are still alive and 52 of these are able to work and are considered cured; the condition of the remaining 20 patients is unsatisfactory with endocrine and psychiatric disturbances being mainly responsible for this. The hormonal upset is usually adrenal cortical insufficiency with symptoms of Addison's disease. Of 39 patients treated with roentgen rays, 20 are healthy and able to work while 12 needed further surgery and irradiation.

The authors call attention to the extrasellar exten-

sion of these tumors as a factor in increased surgical mortality as well as in the reduced efficacy of roentgen therapy. The subsequent course of the tumor seems to bear little relation to whether therapy was by surgery or roentgen ray. Contraindications to roentgen therapy include suprasellar damage and rapid deterioration of vision.—*David Morse, M.D.*

DEL REGATO, J. A., and SALA, J. M. The treatment of carcinoma of the lower lip. *Radiology*, Dec., 1959, *73*, 839–844. (Address: J. A. del Regato, 2200 N. Cascade Ave., Colorado Springs, Colo.)

The results of a study of 531 cases of carcinoma of the lower lip, treated between 1940 and 1953, are reported. In each case the diagnosis of carcinoma was confirmed by biopsy. The overwhelming majority of the tumors were well differentiated: 59 were of the verrucous type and 336 were Grade I carcinomas. There were 103 cases classified as Grade II and only 4 as Grade III. Grading was not done in 29 cases. Only 33 (6 per cent) of the 531 cases in this series presented metastases on admission. In an additional 39 patients, metastases subsequently developed.

Most of the small lesions measuring less than 2 cm. in diameter and without metastases were treated by simple V excision. An absolute three year survival of 81 per cent is reported for this group. Almost identical results were obtained for this size lesion by curie therapy and roentgen therapy.

Lesions 2 to 12 cm. in diameter were treated in most instances by roentgen therapy. The absolute three year survival averaged 73 per cent, being about the same for all therapeutic procedures. Roentgen therapy is regarded as the treatment of choice in the majority of lesions of moderate or large size in the absence of metastases. Surgical removal of larger lesions usually requires cheiloplasty, and the functional and esthetic results may be less satisfactory than those of roentgen therapy. Resection of the primary lesion may be chosen to expedite the surgical treatment of a metastasis or to take care of recurrent carcinoma. Radical neck dissection is recommended as the treatment of choice for cervical metastases. Prophylactic neck dissection is not advocated as a routine procedure.

A total of 103 additional patients were admitted with recurrent carcinomas of the lower lip following treatment elsewhere. In this group there were 26 (25 per cent) with metastases, a proportion four times as great as that observed in those who had received no previous treatment. The curability of this group was inferior to the other group with all methods of treatment.—*Arno W. Sommer, M.D.*

BUSCHKE, FRANZ, and GALANTE, MAURICE. Radical preoperative roentgen therapy in primarily inoperable advanced cancers of the head and neck. *Radiology*, Dec., 1959, *73*, 845–848. (Address: F. Buschke, University of California Medical Center, San Francisco 22, Calif.)

Surgery and radiation therapy are not competitive or mutually exclusive. The well-planned utilization of both forms of treatment can be of great help in the management of properly selected cases. Close cooperation between surgeon and radiotherapist in planning prior to treatment and throughout the entire treatment course is necessary. The most significant progress in radiation therapy during recent years has been due to longer protraction and radiation of shorter wave length. It is possible to introduce high cancerocidal doses with preservation of the vasculoconnective tissues by the judicious use of these two modalities.

The authors selected a number of patients with advanced epitheliomas of the oral cavity and oral pharynx for a planned combination of radical surgery with radical preoperative irradiation. The lesions represented differentiated epitheliomas of pillar, palate, floor of the mouth and gingiva, of a type that can be expected to infiltrate locally or to remain limited to the regional lymphatic areas for a long time, but too extensive for complete removal by primary surgery. The aim was to carry the dose high enough for control of the peripheral portion of the tumor but without attempting to sterilize the more resistant central portion. Fields were large enough to include the peripheral portion of the disease. Radiation therapy was given at one million volts (3.2 mm. Pb half value layer) through a single field. The dose varied between 6,000 and 8,000 r (skin) in thirty-two to fifty-nine days, for a minimal tumor dose (calculated at the most distant edge of demonstrable involvement) of 4,100 to 6,500 r. No attempt was made to include the lymph nodes, palpable or not, unless they happened to be in the field used for irradiation of the primary tumor.

Surgery was done from one to five and one-half months after completion of irradiation. The interval should not exceed two to three months because of the progressive vascular and fibrotic changes. A combined operative procedure was employed whereby the primary lesion was removed *en bloc* with the cervical lymph nodes. Between February, 1957 and February, 1958, 9 patients were accepted for the planned procedure. In 6 instances the treatment was completed as originally intended. In 2 patients the tumor regression was sufficient to warrant anticipation of possible control by irradiation alone and surgery was abandoned. Surgery was abandoned in 1 patient with carcinoma of the tonsil because true tonsillar carcinoma is not considered suitable for this type of operation.

In spite of the heavy preoperative irradiation, there were no surgical complications beyond those associated with this type of surgery when done initially. No fistulas occurred. No conclusions are possible

at this time regarding the final results, but it is emphasized that the risk of surgery in heavily irradiated tissue is not prohibitive.—*Arno W. Sommer, M.D.*

Baclesse, F., Ennuyer, A., and Cheguillaume, J. Est-on autorisé a pratiquer une tumorectomie simple suivie de radiothérapie en cas de tumeur mammaire? (Is one justified to perform a simple tumorectomy followed by roentgen therapy in cases of breast cancer?) *J. de radiol., d'électrol. et de méd. nucléaire*, Mar.–April, 1960, *41*, 137–139. (From: Fondation Curie, Paris, France.)

From 1937 to 1953, at the Curie Foundation, 100 patients with breast carcinoma in Stage I and II underwent simple local tumor excision (tumorectomy) followed by roentgen therapy. The patients so treated had refused radical surgery, or had undergone surgery for an expected benign tumor which at histologic examination proved to be malignant, or were simply referred for this treatment by the surgeon. In all cases, surgery consisted of a simple resection of the tumor, and not the MacWhirter type of mastectomy.

According to the authors, roentgen therapy must be started at the earliest possible time, and not later than the day the sutures are removed. The technique includes the use of 6 or 7 ports so distributed as to deliver a sufficient dose both to the mammary gland and lymph nodes. Minimum doses given were in the range of 4,000 r to the skin, 6,500 r at the tumor site and 6,000 r to the axillary lymph nodes. Each port was usually given 4,000 r with an additional 1,000 to 1,500 r delivered over a small area at the tumor site. The irradiation was protracted over a period of two and one half to three months.

At the end of a five year period, 64 per cent of all the cases so treated were alive and free of cancer, while at the end of ten years 50 per cent, that is, 11 out of 22 cases, apparently were cured. Of the histologically classified Grade I cases, 92 per cent were free of cancer after five years, but with Grades II, III and IV the percentage fell to 53 per cent, showing the importance of the histology on the outcome of the treatment. The age of the patient when the cancer is diagnosed is a paramount factor, since patients under thirty-five years of age have the worst prognosis.

Local recurrences have developed and two were encountered after eight and ten years in the Stage II group. Of the 10 cases with recurrences, 4 had undergone surgery and had survived five years or more, bringing the total five year survival rate to 68 per cent.

Objections to this treatment of breast carcinoma are numerous and well known. However, this technique is not proposed for indiscriminate use in all cases. It is to be considered as an exception and is to be used when patients refuse radical surgery. In Stage I and II cases, and with patients over thirty-five years of age, this technique yields results as good as those obtained by other methods. The present technique also confirms the efficacy of roentgen therapy in the treatment of the breast tumor and the lymphatic extensions. These results corroborate those obtained by using roentgen therapy exclusively (Baclesse) and by MacWhirter's technique of simple mastectomy followed by roentgen therapy.—*Robert L'Abbe, M.D.*

Berger, Simon M., Ingleby, Helen, and Gershon-Cohen, J. Roentgenography and biopsy in mammary cancer. *Radiology*, Dec., 1959, *73*, 891–895. (Address: S. M. Berger, Albert Einstein Medical Center, Northern Division, Philadelphia 41, Pa.)

The authors believe that roentgenography of the breast can achieve a high level of accuracy in the diagnosis of a benign or malignant lesion of the breast. Confirmed studies of a large number of patients have shown that where the findings clearly indicate either a benign or malignant tumor, accuracy is better than 95 per cent. With less definitive roentgenographic findings, particularly in adolescents and some young adults, the diagnosis is less reliable. This occurs in approximately 10 per cent of all breast examinations.

Malignant lesions as small as 0.5 cm. in diameter have been diagnosed and many (48) entirely unsuspected or asymptomatic cancers have been found. The incidence of axillary lymph node metastases in these was only 13 per cent in contrast to 64 per cent in cases diagnosed at surgery.

The cardinal roentgen criteria of carcinoma of the breast are: (1) the presence of an irregular or spiculated opacity, usually seen in scirrhous carcinoma; (2) a rounded opacity with localized notching or infiltration as in medullary or adenopapillary types of carcinoma; and (3) needle-point calcification arranged in clumps, sometimes linearly and at other times widely scattered, frequently noted in duct carcinoma.—*D. N. Dysart, M.D.*

Bloedorn, Fernando G., and Cowley, R. Adams. Irradiation and surgery in the treatment of bronchogenic carcinoma. *Surg., Gynec. & Obst.*, Aug., 1960, *111*, 141–146. (From: Division of Radiotherapy, Department of Radiology, and Division of Thoracic Surgery, Department of Surgery, University of Maryland Hospital, Baltimore, Md.)

This is an encouraging report on the results of a combined method of therapy for bronchogenic carcinoma employing preoperative cobalt 60 teletherapy followed by pneumonectomy. Out of a series of 26 patients for whom combined irradiation-operation treatment was planned, there was a survival rate of 62 per cent with survival times ranging from ten months to forty-four months. Fifty per cent of the group

which received combined irradiation-operation were considered inoperable. Of the 18 who received the combined treatment, 13 are alive and without evidence of disease to the date of this report.

Irradiation was delivered by cobalt 60 supervoltage apparatus achieving a tumor dosage of between 5,500 to 6,000 r. After a two month postirradiation waiting period to allow sufficient time for the acute tissue reaction to subside, a pneumonectomy was performed.

The following interesting facts were noted: (1) a high resectability rate following cobalt 60 therapy; (2) a low incidence of mediastinal lymph node metastases after irradiation; (3) a lowered incidence of distant metastases with this combined method of treatment; and (4) a lack of complications attributable to this combined procedure.—*B. Loitman, M.D.*

FLEISCHER, NORMAN and WALKER, RICHARD. Gastric carcinoma following successful therapy for primary gastric lymphosarcoma. *South. M. J.*, Aug., 1960, *53*, 965–968. (From: Divison of Pathology and Microbiology, University of Tennessee College of Medicine, and City of Memphis Hospitals, Memphis, Tenn.)

The authors report a case of primary gastric lymphosarcoma treated by subtotal gastrectomy and radiation therapy. This was followed in five years by a gastric carcinoma in the residual pouch with regional metastases. Both tumors were confirmed on tissue biopsy. The apparent cure of the previous lymphosarcoma was substantiated on autopsy.

The possible factors leading to the development of the gastric carcinoma are discussed.—*B. Loitman, M.D.*

KENT, STANLEY W., and MCKAY, DONALD G. Primary cancer of the ovary; an analysis of 349 cases. *Am. J. Obst. & Gynec.*, Sept., 1960, *80*, 430–438. (Address: S. W. Kent, 42 Deerings St., Portland, Me.)

This study consists of an analysis of 349 women with previously untreated primary cancer of the ovary seen at the Free Hospital for Women, Brookline, Massachusetts, from 1904 through 1952. The follow-up period was at least five years. The microscopic grading of the tumors was done according to criteria established by Allen and Hertig. The clinical staging is the standard one proposed by Munnel and Taylor.

The most common presenting symptoms were pain, abdominal distention and abnormal uterine bleeding. The five year salvage related to duration of symptoms for a period over six months is 42 per cent and 34 per cent when present for a lesser period of time. This probably indicates that the rapidly growing tumors produce symptoms earlier than those with slower growth. Ovarian cancer is less malignant in younger women and most frequently is found in the forty to fifty-nine year age group.

The serous cystadenocarcinomas were most frequently encountered; 31.3 per cent of them were Grade III, while only 7.1 per cent of pseudomucinous cystadenocarcinomas were so graded. Of patients with Grade I carcinoma, 65 per cent survived five years while only 10.4 per cent with Grade III lived that long. These statistics confirm the prognostic value of grading. The five year survival according to stage is: Stage I, 53.4 per cent; Stage II, 59 per cent; Stage III, 40 per cent; and Stage IV, 10 per cent.

Immediate postoperative irradiation was given to the pelvis and low abdomen of 154 patients, while 173 received no irradiation. The five year survival rate in the former group was 45.5 per cent and in the latter, 32.9 per cent. The significance of the grade of the tumor related to the radiation response was most marked in Grade III. In this grade, survival following surgery alone was 5.2 per cent compared to 18.8 per cent for roentgen irradiation and surgery. Stage I and III showed an increase in survival rate following irradiation, whereas Satge IV did not. Serous and undifferentiated cancers showed good radiation response, while pseudomucinous and granulosa cell tumors in this series did not. Conventional roentgen therapy employing 200 kv. with 0.5 mm. copper filtration and a target distance of 50 cm. was used. Portals of entry were 10×15 cm. or 15×15 cm. front and back, with usually two to the lower quadrants and one to the lower back. Exposures numbered 12 to 20. Total doses at skin level varied from 3,000 to 9,000 r. The dose to the midpelvic plane varied from 1,400 to 2,600 r.—*David Morse, M.D.*

TAKAHASHI, S., and MATSUDA, T. Axial transverse laminagraphy applied to rotational therapy. *Radiology*, Jan., 1960, *74*, 61–64. (Address: S. Takahashi, Hospital of the University of Nagoya, Showaku, Nagoya, Japan.)

Accurate knowledge of the size and location of a lesion is necessary for proper and effective use of rotational radiation therapy. Various methods of determining the external contour of the body cross section have been described but they do not indicate the location, shape and size of the lesion. Axial transverse laminagraphy eliminates this objection in that it provides a roentgen-ray image of a cross section showing both internal and external contour. Such laminagrams are usually made with the patient in the erect position. However, the cross section of the body changes in shape with a change to the supine position. This problem has been eliminated with the development of a unit for supine axial transverse laminagraphy.

The authors describe and illustrate their unit which was developed at the University of Nagoya,

Japan. Basically, it is a replica of the treatment table used in rotation therapy, around which a rotating frame was constructed. This frame, which rotates from 0 to 190°, serves as a mounting for the overhead tube and the synchronized rotating film holder which is beneath the patient. The essential features, therefore, are a rotating tube and film holder, and a stationary table. The central ray of the tube is set at an angle of 20° to the film surface; this produces a cross section considered to be 0.5 mm. thick. There is no distortion except for the magnification (×1.3).

A roentgenogram, or an axial transverse laminagram, made in this manner allows accurate positioning of the patient with the lesion at the center of rotation and permits calculation of the size of the radiation field and the depth dose.—*Edward B. Best, M.D.*

Kilár, Jaromír, and Bek, Václav. Zum Einfluss der Röntgen-Kontaktbehandlung der Hämangiome auf das wachsende Skelett. (The effect of contact roentgen therapy of hemangiomas on the growing skeleton.) *Strahlentherapie*, 1960, *111*, 561–573. (From: Radiologische Klinik der Universität Prag, Prag, Czechoslovakia.)

Of 708 children given roentgen treatment for hemangiomas or nevi between 1945 and 1953, 571 were re-examined in six to thirteen years. Between them they had had 726 hemangiomas and 34 nevi treated: 359 were of the head, 239 of the trunk, and 162 of the extremities. Cosmetic results of treatment were classified as unsatisfactory in 12 per cent of the patients followed. All patients were treated with a contact roentgen therapy unit at 50 kv., 2 ma., 2–4 cm. focal skin distance, and added filtration of 1 or 2.5 mm. Al, but, otherwise, treatment varied considerably. Doses of 300–600 r at intervals of two, four, and six weeks were changed gradually to 100–200 r several times a week and finally to daily doses of less than 100–200 r. Total dose per series of treatments was gradually reduced to 1,000–1,500 r. Forty-six per cent of the children received a single series of treatments, 38 per cent received two series, 12 per cent received three, and 4 per cent received more than four series.

Osseous changes occurred in 9 per cent of the patients; they varied from slight structural changes with shortening of 1–2 cm. of an extremity to orthopedic and functional abnormalities of considerable clinical importance. The frequency of some bone changes increased with the number of series of treatments administered, with the diameter of the area treated, and with decreasing age of the patient. Only 16.7 per cent of the osseous changes developed in children who were over a year old when treated; 59.8 per cent developed in children who were in their first six months.

As a result of this study, the authors (1) no longer treat telangiectatic nevi with roentgen radiation; (2) they believe contact roentgen therapy—and therapy with harder rays or radium—to be contraindicated for hemangiomas near superficial epiphyses, *e.g.*, digits, wrist, elbow, knee; (3) they have limited individual doses of contact roentgen therapy to a maximum of 100–150 r, the total dose in a series to 600–700 r, and the total treatment to no more than two series; and (4) they have employed roentgen examination in all follow-up studies because clinical inspection and comparison of external symmetry between treated and untreated extremities is insufficient to detect skeletal changes caused by treatment.—*Henry G. Moehring, M.D.*

Schwarzwald, Milan, and Vukadinovic, Gjorgje. Die Bedeutung der Elektroenzephalographie bei der Röntgenepilation der Kinderköpfe. (Electroencephalographic findings after roentgen epilation of children.) *Strahlentherapie*, 1960, *112*, 242–250. (From: Dermato-Venerologische Klinik der Medizinischen Fakultät Zagreb und Institut für medizinische Forschungen der Jugoslawischen Akademie der Wissenschaften und Kunst, Zagreb, Yugoslavia.)

Thirty-two boys and girls from four to ten years of age underwent roentgen epilation and had electroencephalography both before and, in most instances, seven days after therapy. Epilation was accomplished by treating each of five fields with 350 r (100 kv., 5 ma., 25 cm. focal skin distance, 0.5 mm. Al filter, half value layer, 1.2 mm. Al); when the patient's head was small, the central field received only 300–320 r.

This epilatory dose caused no change in the electroencephalographic tracings.—*Henry G. Moehring, M.D.*

RADIOISOTOPES

Cheitlin, Melvin D., Bernstein, Robert, and Langdon, Edward A. Varying responses to radioactive iodine (I^{131}) therapy in hyperthyroid patients. *Ann. Int. Med.*, Feb., 1960, *52*, 349–361. (Address: M. D. Cheitlin (MC), Walter Reed Army Hospital, Washington 12, D. C.)

A series of 14 patients, who were treated for hyperthyroidism with I^{131}, is presented, with the following types of responses: (1) euthyroidism after treatment with laboratory tests remaining abnormal; (2) euthyroidism resulting from a large total dose; (3) hyperthyroidism persisting after a large total dose; (4) eventual hypothyroidism after a large total dose; (5) abnormally low laboratory values after therapy with eventual return to normal; (6) temporary hypothyroidism, both clinically and by laboratory tests; and (7) hypothyroidism after a small dose of I^{131}.

These cases demonstrated the variability of response to treatment, the difficulty of dose calculation and the perplexing problem of predicting the ultimate outcome on the basis of short-term laboratory or clinical follow-up. The formula used to treat a majority of these patients was 100 μc I^{131} per gram of the thyroid gland.

The following factors were given to explain the varying responses to treatment: (1) the actual size and weight of the thyroid gland cannot be determined accurately; (2) the formula used assumes equal distribution of the radioactive iodine throughout the gland, which is seldom true; (3) the amount of radioactive iodine in the gland at any one time depends upon the uptake of the radioactive iodine and the time when it is secreted by the gland; this will vary in each individual; and (4) there is a variation in the response of the thyroid tissue to radiation from the radioactive iodine.

In deciding which patients will be re-treated, the clinical state of the patient is the best guide, since the physician cannot rely solely upon the thyroid uptake and protein bound iodine determinations following the first treatment.—*C. W. Ely, M.D.*

Perryman, Charles R., Pavsek, Edward J., and McAllister, John D. Clinical evaluation of radioactive chrome phosphate in the control of malignant pleural and ascitic effusions. *Radiology*, Dec., 1959, *73*, 865–870. (Address: C. R. Perryman, 1400 Locust St., Pittsburgh 19, Pa.)

The authors recommend radioactive chrome phosphate (P^{32}) as the agent of choice in preference to radiogold (Au^{198}), radioyttrium (Y^{90}), and nitrogen mustard in the treatment of malignant pleural and ascitic effusions. The advantage of chrome phosphate is that of a pure beta emitter with a relatively long half life. In addition, the material is noncytotoxic and therapeutically effective in doses of 5 to 10 mc. One of the nitrogen mustard derivatives, thiotepa, merits further clinical investigation.

Radioactive chrome phosphate was used in a total of 60 cases presenting either pleural or ascitic effusion. A dose of 5 mc was given in each case. Definite improvement was observed in 19 of the 38 cases of pleural effusion (50 per cent) and 10 of the 22 cases of ascitic effusion (45 per cent). Based on this experience, the authors now recommend a dose of 10 mc in the abdomen and 5 to 8 mc in the chest.—*Edward B. Best, M.D.*

Albert, Solomon N., Eccleston, H. N., Jr., Fujita, T., Hunter, Charles H., and Albert, Chalom A. Use of magnetic tape for recording radioactivity. *Radiology*, Dec., 1959, *73*, 923–926. (Address: S. N. Albert, Department of Anesthesiology, Washington Hospital Center, Washington 10, D. C.)

Radioactive isotopes are frequently used as tracer material for diagnostic purposes. Sometimes interpretation of disappearance curves is rendered difficult because of weak doses or inadequate settings of the rate meter as to scaling and time factors. To obviate loss of valuable data, commercial tape recorders have been employed to register disintegration impulses. This does not interfere with the routine counting system.

Details of wiring Nuclear-Chicago and Picker meters are given; a Norelco tape recorder was used. Tape recordings may be replayed by connecting to the input of a rate meter or scaler. By varying the replay speeds, poor quality curves can be improved for easier and better interpretation.

Three schematic drawings and three reproductions of cardiac output dilution curves using this system are included.—*J. C. Moore, M.D.*

Holsti, Lars R., and Voutilainen, Antero. Über kombinierte Röntgen- und Radiophosphorbehandlung bei Mycosis fungoides. (The combined roentgen and radioactive phosphorus treatment of mycosis fungoides.) *Strahlentherapie*, 1960, *111*, 139–148. (From: Strahlenklinik und Dermatologische Klinik der Universität, Helsinki, Finland.)

After treating 5 patients with mycosis fungoides by a combination of radioactive phosphorus and roentgen radiation, the authors permit themselves no far-reaching conclusions, but feel that:

(1) P^{32} is a useful therapeutic aid in treating patients with mycosis fungoides when the foci of disease are generalized, slowly growing, and not producing many or large tumors. It seems to have no effect in the rapidly growing, malignant forms, particularly when biopsy shows increased capillary formation in the superficial layers of the skin.

(2) P^{32} should be given at intervals of ten to fourteen days, by mouth or vein, in doses of 5–9 mc to a total of 27–29 mc. If it is effective and if the patient's blood is not seriously depressed by the therapy, this treatment can be repeated for recurrences.

(3) Local roentgen therapy was effective in all 5 patients; it should be used, following P^{32} therapy, to treat masses or local infiltrations.

Four of the 5 patients were benefited by P^{32} therapy (1 was improved dramatically). The fifth patient had extensive tumors and did not benefit. Radioactive phosphorus therapy caused anemia in 2 patients; 1 of these also developed a thrombocytopenia.—*Henry G. Moehring, M.D.*

Hawliczek, F., Langner, E., and Seemann, D. Zur Frage der zerebralen Radioangiographie. (Cerebral radioangiography.) *Strahlentherapie*, 1960, *111*, 280–285. (From: Sonderabteilung für Strahlentherapie des Krankenhauses der Stadt Wien Lainz und Neuro-

logische Abteilung des Altersheims der Stadt Wien Lainz, Austria.)

When 50 μc of radioiodine-tagged human serum albumen is injected into an antecubital vein, a scintillation counter over the confluence of the cerebral venous sinuses records a maximum count within 15–20 seconds in normals, 22–35 seconds in patients with obvious cerebral vascular disease, and 18–23 seconds in borderline cases. The curves for the normal subjects showed a rather abrupt rise and fall, while the curves for the definitely abnormal patients were much flatter.

The next step was the simultaneous recording of counts over the carotid artery and the cerebral venous confluence after injection of the radioactive serum albumen. The authors found that count-maxima occurred at longer intervals than those reported from serial angiography (8.5–13.0 seconds from the carotid injection until clearing of the cerebral vessels for the normals, and 12.5–16.0 seconds for the arteriosclerotic patients).

Five to ten minutes after administration of such vasodilators as ethylendiamine and purines, the time from antecubital injection to the maximum count at the venous confluence was lengthened. The authors assume that this indicates a greater cerebral vascular cross section, but they disclaim firm conclusions about the mechanism of this effect.—*Henry G. Moehring, M.D.*

MISCELLANEOUS

Stone, Robert S. The Gordon Richards Memorial Lecture 1960: Factors influencing maximum permissible doses of radiations. *J. Canad. A. Radiologists*, June, 1960, *11*, 26–34. (From: Department of Radiology and AEC Radiological Laboratory, University of California School of Medicine, San Francisco, Calif.)

In his Lecture Dr. Stone interprets the "permissible doses" set forth by the International Commission on Radiological Protection of which he is a member. There are different maximum permissible doses given for exposure of the total body, extremities, and separate organs, as well as for various groups in the community.

In 1934 the International X-ray and Radium Protection Commission meeting in Zurich determined from all known facts a "tolerance dose" of 0.2 r per day. In 1936 the Advisory Committee on X-ray and Radium Protection of the United States in National Bureau of Standards Handbook 20 lowered its "tolerance dose" to 0.1 r per day, because in the United States doses were measured in air as against skin dose measured on the Continent plus the fact that more penetrating rays of higher energy were being employed in the United States.

The early radiologists and physicists based their "tolerance dose" on the biologic measure of a skin erythema which is (1) a threshold type of reaction and (2) dose-rate dependent. Since with fractionation of dosage a skin erythema could be prevented, it was believed that daily small repeated doses were "tolerable."

After Muller demonstrated that roentgen rays produced gene mutational effects which were additive regardless of dose rate or fractionation, it was realized that this was a linear or non-threshold type of reaction. If this be true then there is no "tolerable" dose, and the setting of a maximal permissible dose becomes a matter of judgment when deciding upon an "acceptable risk." Three general effects, (1) life shortening, (2) leukemia induction, and (3) genetic effects, have important bearings on the permissible dose. Animal experimentation and statistical analyses in each of these categories find expert opinion on both sides of the question as to whether there is a threshold. Insofar as genetic effects are concerned, Dr. Stone opines we should assume that there is no threshold and keep gonadal exposure very low.

The sensitivity of the embryo and fetus with regard to malformations and malignancies in childhood presents for women in the reproductive age a special hazard. The International Commission on Radiological Protection has given recommendations of maximal permissible exposure in most circumstances except in medical radiology. Here they feel the physician should balance the good to be accomplished against any possible harm. All precaution should be taken to keep gonadal exposure to the lowest possible levels consistent with the patient's medical needs.—*B. Loitman, M.D.*

Seelentag, Walter, and Klotz, Erich. Die Strahlenbelastung der Bevölkerung durch Leuchtzifferblätter von Uhren. (Radiation exposure of the population from illuminated watch dials.) *Strahlentherapie*, 1959, *110*, 606–621. (From: Institut und Poliklinik für Physikalische Therapie und Röntgenologie der Universität München und Röntgenabteilung der Medizinischen Klinik der Städt. Krankenanstalten, Augsburg, Germany.)

Measurements on 38 different watches and clocks with illuminated dials demonstrated an average radium equivalent of 0.12 microgram for large alarm clocks, 0.08 microgram for travel alarm clocks, 0.03 microgram for small alarm clocks, and 0.04 microgram for wrist watches. Variations from the average were wide, up to five times the average value.

The radiation dose to the user of these timepieces averaged: 0.15 microroentgen per hour from the large alarm clocks, 0.10 microroentgen per hour for travel alarm clocks, 0.05 microroentgen per hour for small alarm clocks, and 0.6 microroentgen per hour for wrist watches. The source-user distance was assumed to be 1 m. for the alarm clocks and 30 cm.

for the wrist watches. The local dose to the forearm from a wrist watch averages 300 microroentgens per hour. These doses pose no threat of somatic damage to the user.

Sales personnel in a large watch store received a dose of up to 75 microroentgens per hour, an annual dose of 90 milliroentgens, approximately three-fourths of the natural background radiation level. Neither does this pose a threat of somatic radiation damage and, reckoned on the basis of the entire population, the genetic hazard also disappears.

The dose to the population from illuminated dials is estimated at 2.6 milliroentgens per person per year, about 2 per cent of the dose from natural background radiation, no genuine genetic hazard.

Whether this radiation dose is acceptable in return for whatever advantages illuminated dials present is beyond the scope of this investigation.—*Henry G. Moehring, M.D.*

Ritz, Victor H. Design of free-air ionization chambers for the soft x-ray region (20–100 kv.). *Radiology*, Dec., 1959, *73*, 911–922. (Address: National Bureau of Standards, Washington 25, D. C.)

The present study was undertaken to supplement the design of the standard free air ionization chambers (as described in the National Bureau of Standards Handbook 64), modified to measure ionization in the soft roentgen-ray region between 20 and 100 kv. Use of the standard free air chambers requires consideration of a number of factors. First, the roentgen is defined in terms of the ionization produced by the interaction of a roentgen-ray beam with a specified mass (volume) of dry air. This volume is influenced by three factors: the size of the diaphragm through which the beam enters, the length of the collector plate, and the electric field between the high voltage plate and grounded collector plate. The grounded lead box enclosure of the chamber causes distortion of this electric field however, and guard plates must be used to eliminate it. These plates themselves will also cause a certain amount of distortion, especially when they are close to the edge of the collector plate or when they are too widely spaced. Secondly, electrons produced by the interaction of the roentgen-ray beam and the air outside the collecting region will travel through the collecting area and produce ionization. Conversely, electrons produced within the collecting area will pass outside the area before producing ionization. Thus the proper design of the free air chamber requires a knowledge of the range of these primary electrons. Conditions may also exist where photons scattered from the primary beam reach the collecting area and produce ionization. This scattered photon contribution must be determined and subtracted from the total ionization measured by the chamber.

Also, a correction must be made for the attenuation of the roentgen-ray beam by the air between the diaphragm and the center of the collector. This correction becomes quite large when measuring soft roentgen rays. Decreasing the length of the air path between the diaphragm and collector plate will help nullify this factor but, in so doing, there is an increase in the distortion of the electric field caused by the guard strip system. As a result, the reduction of the air path distance is limited by its field distortion effect.

The present study deals with the measurement and correction of the above mentioned physical factors; namely, the distortion of the electric field in the collecting region by the guard strip system, the range of primary electrons and the scattered photon contribution, and other corrections such as air attenuation. The apparatus is described in detail and several schematic drawings are presented to show the experimental free air chamber which was used. The field distortion study is described and the results are recorded graphically. The method for determining primary electron losses is outlined and a series of graphs show the results at varying kv. energies and filtrations. Data are also given to show the scattered photon contribution at various voltages and at varying radii (cm.) from the roentgen-ray beam corrected to zero diameter. Reduction of the air path between the chamber diaphragm and the collector plate to a distance of 5 cm. was possible as a result of these studies. Values for air attenuation in this 5 cm. distance chamber were found to be about 0.15 per cent higher than similar values established by Day and Taylor using the standard free air chambers. Corrections for the humidity of the air may amount to plus 0.3 per cent in the soft roentgen-ray region under ordinary laboratory conditions. Methods of calculating this correction are found in Handbook 64.

The maximum errors in the factors investigated here may be summarized as follows: field distortion and errors in measuring the length of the collector ± 0.2 per cent, electron losses ± 0.1 per cent, scattered photon contribution ± 0.2 per cent and air attenuation ± 0.2 per cent. These values, combined with the estimates in Handbook 64 for uncertainties in the diaphragm area, charge measurement, etc. yield a probable limit of error of ± 0.5 per cent for the determination of exposure dose in r in the soft roentgen-ray region.—*Z. Petrany, M.D.*

THEODORE R. MILLER, M.D.